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HANDBOOK OF UTILIZATION OF AQUATIC PLANTS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

HANDBOOK OF UTILIZATION OF AQUATIC PLANTS

A Review of World Literature

by

E.C.S. Little
Kerikeri, Bay of Islands
New Zealand

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1979

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PREPARATION OF THIS DOCUMENT

The Fisheries Department of FAO has a special interest in the control and utilization of aquatic plants owing to the frequency with which such vegetation interferes or is thought to interfere with fish production in inland waters, especially in the tropics. Dr. E.C.S. Little's handbook, Utilization of aquatic plants (1968) proved very useful to workers concerned with such problems, but is no longer available. Dr. Little has revised and expanded the handbook for FAO to bring it up to date.

Distribution

FAO Department of Fisheries
FAO Regional Fisheries Officers
FAO Country Representatives and
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Bibliographic reference

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Handbook of utilization of aquatic plants

Manuals. Aquatic plants. Exploitation.
Bibliographies. Literature reviews.

ABSTRACT

There are many kinds of aquatic plants which are, or could be, utilized for such purposes as feeds, fuel, building materials, soil improvement and water purification. As some of these plants can also be a nuisance to fisheries, water transportation, or water supply systems, it is desirable to find ways of controlling such vegetation by harvesting and using it. The water hyacinth, Eichhornia crassipes, is a well-known example of a nuisance plant which could be used in many ways.

This volume provides a comprehensive reference to all of the important aspects of utilization of aquatic plants, listing, with annotations, more than 250 books, scientific papers and other publications. The largest section concerns the chemical composition and productivity of various species and a large number of analytical results are quoted. Also included are sections on harvesting and protein extraction, as well as on the various types of uses of these plants. An author index and an index of plants are included.

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I. INTRODUCTION

The first edition of this handbook contained a review of the literature concerned with the utilization of fresh-water aquatic plants going as far back as 1917. The objective was to assemble the ideas and experimental results of those authors and research workers who considered that aquatic plants could, or should, be looked upon in one way or another as useful crops. That this concept was rather novel at the time was indicated by the relatively small number of publications found on the subject. A total of 49 references was listed in the table of contents of which only about 30 were complete papers; the remainder were articles taken from papers or books on wider or related topics. Inevitably a few papers were overlooked.

Since 1968 about five times as much information on the use of aquatic weeds has been released as during the whole previous history of the literature, making a revision of the first edition well worth while. The large number of references also makes it impracticable to reproduce papers more or less verbatim, as in the first edition.

An attempt has been made here to summarize the published material as well as to review it. Tabulated material has, in many cases, been condensed or rearranged and analyses have been selected from the considerable amount of data available. In those cases where the complete paper has not been available, frequent use has been made of the invaluable Commonwealth Agricultural Bureaux publication, Weed Abstracts. There is a danger of presenting extracts which, read out of context of the complete paper, may perhaps be interpreted rather differently. This risk has been accepted, and sufficient information is given to reveal the range of each paper.

More than 250 papers are cited, including those in the first edition (which are marked *). The annotated references are given in alphabetical order of authors within each chapter.

The handbook has been divided into chapters on plant analyses, methods of harvesting, and various aspects of use of aquatic plants. No attempt has been made to cover the age-old uses of aquatic plants such as for weaving and thatching, and only brief reference is made to industrial uses such as for paper making, as these aspects are well covered in the established literature. For example, Boyd (1974) has summarized the uses of reeds which represent, so far, the most heavily utilized aquatic plant. In Romania, where the industry is most fully developed, harvests have reached 200 000 t/year (Rudescu, Niculescu and Chivu, 1965).

This edition also includes a section on water purification. Many water weeds respond to the high quantities of nutrients such as nitrogen or phosphorus in polluted water through greatly increased growth. This is generally viewed with dismay as the vegetation can create various nuisances, but now, with pollution becoming an increasingly serious problem itself, there is an awareness that aquatic plants may be useful as a means of extracting contaminants from water. They could provide an alternative to more expensive, conventional means of water purification and at the same time be exploited as a resource, thus paying for the costs involved. Toxic industrial pollutants, e.g., heavy metals, may also be extracted from water by plants. So the proposals of early enthusiasts that aquatic plants, used in this way, could be classed as useful crops rather than notorious weeds are being increasingly accepted.

A survey of the losses caused by aquatic weeds has been made by the United States Agency for International Development (1971) in Ghana, Sudan, Zambia, Thailand, Guyana and the U.S.A. The survey points out how serious the need to control aquatic weeds may be for developing countries which are not able easily to absorb the costs of control. Thus to be able to convert such concentrations of plants to useful purposes instead of just accepting the costs of their destruction could be of considerable importance to the economies of such countries.

A method of assessing losses due to aquatic weeds, based on measurement of water reduction and the consequent value of loss of crop, has been described by Timmons (1971). This is one way to help in arriving at a decision as to how much expenditure is worth while in attempts to control the weeds and whether the costs of harvesting for utilization are justified.

The water hyacinth, Eichhornia crassipes, is the best known and most notorious aquatic plant. It has received by far the most attention in the literature because this extraordinary tropical weed is more widespread than any other.

In the Sudan the water hyacinth is of exceptional importance, threatening as it does the navigability of a main artery of the country, the White Nile. In 1975 the Sudan National Council for Research, Agricultural Research Council, in cooperation with the United States National Academy of Sciences, organized a workshop on the management of water hyacinth, of which its utilization was an important aspect. Delegates from Egypt, Ethiopia, Indonesia and Mozambique participated.

A similar workshop in Guyana was organized in 1973 by the National Science Research Council in cooperation with the United States National Academy of Sciences. Methods of processing water hyacinth for animal fodder and for fertilizer were discussed. The utilization of Pistia stratiotes was also discussed.

A detailed study of how aquatic plants could be usefully employed to play a part in the agricultural schemes of rich and poor countries has been advocated by a few writers for many years, and this interest has increased. Many plants, once seeming to threaten agriculture by impeding water flow and wasting water, may be shown to have characteristics which will enable them to provide a valuable complement to agriculture.

It is hoped that this handbook will supplement the literature by helping those who wish to control and to make use of these plants, especially the most dangerous ones, and thus convert them from enemies to useful friends.

Acknowledgements

I would like to thank the Department of Fisheries, FAO, for their encouragement and assistance in the preparation of this handbook, and also the Librarians of the Biology and Science Libraries of the University of Auckland, New Zealand, and of the Central and Mt. Albert Libraries of the Department of Scientific and Industrial Research, New Zealand, for their assistance in literature searches.

Dense infestation of water hyacinth growing on margin of Inya lake, Rangoon, Burma

Water weeds on Kirkgözlü lake, Antalya, Turkey

II. REVIEWS AND BIBLIOGRAPHIES

The increasing interest in the utilization of aquatic plants is shown not only in the many published papers but also in the number of reviews and bibliographies produced since the first edition of this handbook was prepared.

The biology of aquatic vascular plants, by C.D. Soulthorpe (1967) is an important text, containing a wealth of information. It includes a review of the literature on ancient uses of aquatic plants for food and medicines, and a chapter on the economic and aesthetic value of these plants.

D.S. Mitchell (1974) edited Aquatic vegetation and its use and control, which contains a section (pp. 107-15) on utilization of aquatic plants, by C.E. Boyd. It makes no attempt to cover all aspects of the subject but should be consulted; in it many of the more important papers are briefly cited.

N.W. Pirie, well known for his work on the extraction of protein from plants for human and animal consumption, edited the IBP Handbook, "Leaf protein, its agronomy, preparation, quality and use" (1971). This text also contains a chapter by C.E. Boyd on the literature of the leaf protein content of aquatic plants and can be compared with data for terrestrial plants presented in other chapters.

Water hyacinth has been reviewed by A.H. Pieterse (1974). All aspects of the plant, including its utilization, are briefly covered, with a total of 215 references. A useful bibliography is provided. It is divided into sections on distribution; general botany; environmental factors associated with growth and flowering; direct effect of environment; dormancy and germination of seeds; production and regeneration; mechanical, chemical and biological control; chemical composition; utilization (animal fodder, compost and mulch); mineral removal from polluted water, and industrial uses such as paper making, wicker and basket work, soap, gas and alcohol production.

In 1978 Pieterse revised this work in the same style but giving 666 references, which he grouped into eight categories: general information (25 references); general botany, ecology and spread (226 references); chemical and mechanical control (143 references); biological control (139 references); chemical composition and use as fodder (63 references); use as compost and mulch (22 references); production of chemical materials and energy (16 references); use for mineral removal from polluted water (32 references). The remarkable increase in the literature on this plant indicates the concern felt for it as a pest and, more recently, as a potentially useful crop.

An earlier review on water hyacinth by A. Sharma (1971) summarized the work done on its utilization with a total of 50 references and can be read as an introduction to the subject. The author estimates the total area under water hyacinth in India at 200 000 ha which could produce about 5 million tons of compost. He calculates that it could be harvested at a profit for use as fertilizer. Other aspects of use included are: as food for animals, raw material for industry, and a source of gases, proteins and other chemicals. He concludes by suggesting that regular harvesting would lead to extermination of the weed from enclosed areas which could then be used for cultivation of the valuable plant crop Trapa natans (water chestnut).

K.M. Jagadeesh and C.S. Lakshminarayana (1971) have also contributed a brief review on water hyacinth control and utilization (four references), as have V. Ramachandran et al. (1971) with 55 references.

O.P. Gupta and P.S. Lamba (1976) reviewed the use of aquatic plants for fodder, compost, protein carotene, fish food, pulp and paper, culture for yeast and antibiotics, medicinal ingredients, and for pollution abatement (23 references). The authors urge that interdisciplinary research is needed for the appropriate commercial exploitation of

aquatic plants. Such an approach alone could ensure adequate control of important aquatic weeds in the tropics and subtropics. (From Weed Abstracts)

J.L. Fox and H.S. Prentice (1975) have reviewed methods of harvesting aquatic plants with many references. (From Weed Abstracts)

A recent review from the U.S.A. by R.P. Bates and J.F. Hentges (1976) has a bibliography of 71 papers. The authors, after discussing methods of control of aquatic weeds, consider the alternative of cultivating them for use. The possibilities of grazing the plants by manatees or by fish are examined. Aspects of harvesting and subsequent use for compost, or directly as animal or even human food, are also mentioned.

An early review, also from the U.S.A., which should be read in conjunction with Bates and Hentges, is by Nelson and Palmer (1938). The detailed experimental results reported are supported by references to about 100 papers containing data on the vitamin and protein content of a range of aquatic plants and their consequent potential importance in animal nutrition.

C.E. Boyd (1972) has prepared a comprehensive bibliography on aquatic weed use with 233 references which he has classified into seven groups: chemical composition and nutritive value; nutrient removal; productivity and standing crop; ecology and life history; identification; aquatic plant nutrition and physiology; nutrient relationships in aquatic environments.

In 1976 the Weed Research Organization of the Agricultural Research Council, U.K., published an annotated bibliography (No. 92) containing selected references on the utilization of aquatic plants covering the period 1969-75. Each reference cites the relevant summary from the Commonwealth Agricultural Bureaux Journal, Weed Abstracts, and where these were not available at the time a specially prepared summary is given.

Weed Abstracts is itself a useful source, because it publishes a section on utilization of weeds, including aquatic weeds.

Herbivorous fish can control and utilize aquatic plants. Of these the grass carp (Ctenopharyngodon idella) is the best known and the subject of numerous papers. FAO has published a bibliography of 243 references (Nair, 1968). In 1976 the Weed Research Organization of the Agricultural Research Council, U.K., published a bibliography of 162 references, covering the period 1957-76, on the use of herbivorous fish.

In New Zealand, Hughes (1976) reviewed all aspects of local aquatic weed research. Brief reference is made to seven papers (five unpublished) on the possibilities of harvesting the weeds infesting New Zealand lakes and using them for compost or for stock feed. General conclusions were unfavourable.

The United States National Academy of Sciences published in 1976 a comprehensive book of 175 pages on making use of aquatic weeds. It is directed towards developing countries and contains 4-page summaries in Spanish and French. There are 14 chapters covering all aspects of direct use of the plants, including: foods for various fish, birds and mammals; methods of harvesting and drying, and subsequent use for animal and human food; use for soil additives; for industrial purposes, including energy, and for purification of polluted water. Each chapter details the need for further research, gives relevant literature references, and lists individuals and organizations around the world which are involved in research. The book is well illustrated. The theme is of enthusiastic encouragement to people in developing countries to harvest their vigorous and often dangerous aquatic plants for useful purposes, rather than incur the expense of using herbicides and the mechanical control methods which may be more feasible and acceptable in developed countries.

The review and bibliography presented in this handbook are necessarily incomplete; with the advance of research it will soon require revision. However, it has been brought up to date as far as practicable, and in more detail than other contributions so far published.

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Reed boat in a channel cut through weeds in
Lake Titicaca, Bolivia

III. WATER, MINERAL AND PROTEIN CONTENT AND PRODUCTIVITY OF AQUATIC PLANTS

The ingredients, other than water, of aquatic plants are similar to those in plants adapted to growth on dry land. The literature contains the results of numerous analyses taken of different species growing in a range of habitats in many countries. A general criticism against the usefulness of aquatic plants is that their high water content makes them inconvenient to harvest and also unsuitable as fodder for livestock. Moreover, it is often alleged that the plants are low in useful nutrients.

Therefore a study of these various results should be interesting and helpful to those considering the utilization of aquatic plants for their own particular needs.

Probably the most comprehensive analyses of aquatic plants has been done by C.E. Boyd, U.S.A., whose work will be repeatedly noted in the following pages. This work has culminated in an extensive review (Boyd and Scarsbrook, 1975) in which the data from 35 papers, all on work in the U.S.A., have been tabulated. Anyone studying the overall range of aquatic weed analyses should have a copy of this paper.

A brief but useful review on nutrient uptake by aquatic plants by J.J. Gaudet appears in a chapter in Mitchell (1974).

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Abdalla, A.A. and A.T. Abdel Hafeez, 1969 Some aspects of utilization of water hyacinth (Eichhornia crassipes). PANS, 15(2):204-7

Water hyacinth analysis (% fresh weight):

water = 90.2; N = 1.03; P = 0.42; K = 1.81; Ca = 0.02

The authors point out the high P content in water hyacinth compared with 0.24% in alfafa (lucerne).

*Agrupis, F.M., 1953 The value of water hyacinth as silage. Philipp.Agric., 37(1-2):50-6

Water hyacinth analyses:

	%		%
moisture	90.7	crude protein	0.9
carbohydrates (N-free extract)	3.9	crude fats (ether extract)	0.4
crude fibre	2.2	ash	2.0
Ca	0.3	P	0.1

Calorific value for every 100 g = 23.0.

*Alford, L.W., Alligator weed - a good cattle food. Chemurg.Dig., 2(9):10-2 1952

Alligator weed (Alternanthera philoxeroides) - analysis of dry matter (100°C) (%):

moisture	12.0	$Al_2O_3 + Fe_2O_3$	0.79
ash	12.0	CaO	0.29
fat and oil	1.4	MgO	0.06
crude protein	6.4	dextrose	2.8
crude fibre	7.5	invert sugar	6.2
N-free extract	60.8	sucrose	3.2

Air-dry moisture = 80%

Allenby, K.G., The manganese and calcium content of some aquatic plants and the water 1967 in which they grow. Hydrobiologia, 29:239-44

Analyses of Mn, Ca and ash of a range of aquatic plants (mean of several analyses):

Species	% DM Ash	% DM Mn	% DM Ca	% Ca in ash
Alisma plantago	10.8	0.05	1.2	11.0
Sparganium ramosum	7.8	0.05	1.1	13.8
Carex acutiformis	4.9	0.02	0.3	6.3
Potamogeton natans	7.1	0.15	0.9	12.5
Sagittaria sagittifolia	9.8	0.05	1.0	10.0
Elodea canadensis	12.8	0.29	1.6	12.8
Lemna minor	12.1	0.40	1.8	12.3
L. trisulca	13.6	0.31	1.5	10.7
L. gibba	19.0	0.17	1.1	5.8

The author comments that the Mn content of aquatic plants is several times greater than land species. There appeared to be no correlation between the amount of Mn in the plants and the water in which they grow. He also noted that the Ca to ash ratio of E. canadensis, S. ramosum and A. plantago is less than that of the water.

Allenby, K.G., Some analyses of aquatic plants and waters. Hydrobiologia, 32:486-90 1968

Analyses (% or ppm dry weight) of a range of aquatic plants compared with the water in which they were growing (mean of several analyses):

Species	Ca		Cu		N	
	Water	Plant	Water	Plant	Water	Plant
	ppm	%	ppm	ppm	%	%
Lemna minor	45	1.55	0.03	25	2.9	3.7
L. gibba	48	1.05	0.05	33	1.2	3.9
L. polyrhiza	41	1.43	0.02	19	3.5	4.6
L. trisulca	28	1.25	-	-	1.7	3.7
Elodea canadensis	27	1.22	-	-	1.0	3.2
Potamogeton obtusifolius	25	0.48	-	-	-	-
P. pectinatus	92	2.6	-	-	-	-
P. perfoliatus	92	0.7	-	-	-	-
Hottonia palustris	84	0.7	-	-	-	-

The author draws attention to the high N. content of L. polyrhiza which was growing in high nitrogen water.

He also notes that chloride content of L. minor appeared to decrease with increasing chloride content of the water, while with L. polyrhiza the reverse appeared to be the case. With E. canadensis there appeared to be no relationship.

Anderson, R.R., R.G. Brown and R.D. Rappleye, The mineral content of Myriophyllum
1966 spicatum L. in relation to its aquatic environment. Ecology, 47:844-6

Analyses of Myriophyllum spicatum when grown in fresh water and in brackish water (ppm fresh weight):

Element	Source	Fresh water	Brackish water
Ca	water	10	150
	M. spicatum	350	250
K	water	10	125
	M. spicatum	2 700	1 600
Na	water	6	2 700
	M. spicatum	1 200	2 100
Mg	water	20	400
	M. spicatum	50	140

M. spicatum analyses (% DM)

	Fresh water	Brackish water
N	3	2
K	0.4	0.4
S	0.4	0.3

The authors comment that M. spicatum appears to be capable of regulating salt uptake independently of concentrations in the aquatic environment. It can tolerate salt concentrations up to a maximum of 15 000 ppm.

*Bailey, T.A., Commercial possibilities of dehydrated aquatic plants. Proc.Annu.Meet.
1965 South.Weed Sci.Soc., 18:543-51

Citation of unpublished analyses of the dry matter of aquatic plants compared to common animal foods containing xanthophyll:

Plant or food	Protein %	Fibre %	Xanthophyll ppm
Ceratophyllum sp.	18.3	16	922
Elodea densa	16.8	14	820
Myriophyllum exalbescens	21.1	11	1 160
Yellow corn	8-9	-	13-22
Alfalfa meal	16-21	-	175-400
Corn gluten meal (mean)	50	-	176-320

Analyses (mean of different harvests):

	Protein %	Fibre %	Ash %	Xanthophyll ppm
Ceratophyllum sp.	18	15.5	19	420
E. densa	15.5	14	18.5	560
M. exalbescens	24.5	13	19	1,030

Estimated annual yields of E. densa = 6.5 tonnes/ha
and of M. exalbescens = 8.4 tonnes/ha

The author concludes that it would appear that these dehydrated plants will average 840 mg of xanthophyll per kg, about 19% protein, and about 12% fibre.

Bock, J.H., 1969 Productivity of the water hyacinth, Eichhornia crassipes (Mart.) Solms. Ecology, 50(3):460-4

Water content of water hyacinth (derived from the mean of 82 determinations) was 93.4%. The author notes that this content remained nearly constant throughout the growing season. After reviewing literature from several countries on daily production she points out that, in California, water hyacinth can, in spite of winter frosts, produce at a rate comparable with growth in the tropics.

Boyd, C.E., 1968 Fresh water plants: a potential source of protein. Econ.Bot., 22:359-68

The author has carried out analyses of many aquatic plants. Tannin content was included. He cites work at Auburn University, Alabama, U.S.A., which showed that high tannin interferes with protein digestibility. Most high quality forage crops contain less than 2.3% (dry weight) of tannin. Thus plants containing more than 6-7% would be so low in digestibility as to be of little food value. The following table is quoted:

Dry Matter (D.M.) and Proximate Nutritional Analyses of Aquatic Plants

Species	n[1]	D.M. (%)	Dry weight basis: Ash (%)	Crude protein (%)	Crude fat (%)	Cellulose (%)	Tannin (%)	Caloric content (Kcal/g)
Submersed vascular plants								
Myriophyllum brasiliense	4	13.7	11.2	14.1	3.78	20.6	11.0	3.69
M. spicatum	2	12.8	40.6	9.8	1.81	18.8	3.2	2.47
M. heterophyllum	1	10.0	15.5	8.5	2.67	32.7	3.2	3.35
Potamogeton diversifolius	1	9.8	22.7	17.3	2.87	30.9	2.0	3.40
P. crispus	2	11.8	16.0	10.9	2.85	37.2	7.2	3.61
P. nodosus	1	15.8	10.9	11.2	3.62	21.7	3.4	3.77
Elodea densa	3	9.8	22.1	20.5	3.27	29.2	0.8	3.35
Ceratophyllum demersum	2	5.2	20.6	21.7	5.97	27.9	1.9	3.71
Najas guadalupensis	1	7.3	18.7	22.8	3.75	35.6	1.4	3.55
Hydrotrida caroliniana	2	6.4	22.7	9.7	3.85	29.5	2.5	3.32
Cabomba caroliniana	1	7.0	9.6	13.1	5.42	26.8	15.6	3.78
Eleocharis acicularis	3	11.1	9.9	12.5	3.59	27.9	2.0	3.91

[1] Number of samples.

Species	n	D.M. (%)	Dry weight basis: Ash (%)	Crude protein (%)	Crude fat (%)	Cellulose (%)	Tannin (%)	Caloric content (Kcal/g)
Emergent vascular plants								
Polygonum hydropiperoides	4	19.2	7.8	11.9	2.39	26.9	6.8	4.06
P. sagittatum	1	15.0	8.0	11.0	2.99	31.2	5.9	4.01
P. pensylvanicum	1	23.9	7.4	10.3	2.77	23.1	6.8	3.90
Jussiaea peruviana	2	18.5	7.8	9.4	7.10	27.5	15.6	3.89
J. diffusa	1	13.1	11.1	10.7	3.76	24.2	12.6	3.68
J. decurrens	4	11.8	11.7	19.1	3.93	29.5	4.1	3.88
Justicia americana	6	15.0	17.4	22.9	3.40	25.9	1.8	3.98
Orontium aquaticum	5	13.2	14.1	19.8	7.85	23.9	3.3	3.74
Sparganium americanum	1	10.9	11.4	23.7	8.11	20.5	3.7	4.17
Alternanthera philoxeroides	6	14.5	13.9	15.6	2.68	21.3	1.2	3.46
Sagittaria latifolia	6	15.0	10.3	17.1	6.71	27.6	2.5	4.12
Typha latifolia	3	22.9	6.9	10.3	3.91	33.2	2.1	3.69
Brasenia schreberi	4	10.4	8.8	12.5	4.71	23.7	11.8	3.79
Nymphoides aquaticum	3	10.3	7.6	9.3	3.29	37.4	2.9	3.95
Nymphaea odorata	5	13.7	9.2	16.6	5.38	20.7	15.0	3.95
Hydrolea quadrivalvis	1	11.0	9.3	11.1	3.85	22.8	2.9	4.00
Nuphar advena	3	12.0	6.5	20.6	6.25	23.9	6.5	4.30
Saururus cernuus	3	21.9	11.3	12.1	6.85	25.3	7.0	4.28
Hydrochloa carolinensis	3	19.4	6.1	10.4	2.78	22.0	0.8	4.10
Nelumba lutea	2	16.8	10.3	13.7	5.25	23.6	9.2	3.74
Algae								
Spirogyra sp.	10	4.8	11.7	17.1	1.76	10.0	-	-
Pithophora sp.	17	14.9	27.4	16.7	6.04	17.6	0.5	2.89
Chara sp.	18	8.4	35.8	17.5	1.63	23.8	0.4	2.58
Rhizoclonium sp.	5	-	19.8	21.5	4.66	19.2	-	-
Hydrodictyon reticulatum	5	3.9	11.9	22.8	7.08	18.1	0.8	3.94
Oedogonium sp.	3	-	12.7	16.5	2.39	29.4	-	-
Nitella sp.	5	4.1	17.9	16.9	2.47	40.9	0.2	3.36
Lyngbya sp.	3	-	17.2	31.3	-	22.2	-	-

Five selected species were analysed, and their crude protein content analysed into amino acid content:

Species	Analyses (% DM): Ash	Crude fat	Cellulose	Caloric content (Kcal/g)
Justicia americana	8.2	9.4	1.6	5.2
Orontium aquaticum	7.4	14.9	2.6	5.6
Nymphaea odorata	4.2	8.6	8.3	4.9
Sagittaria latifolia	4.2	16.6	-	5.4
Alternanthera philoxeroides	12.5	7.7	5.9	4.6

Amino Acid Analysis (% DM)

Species	Argi-nine	Histi-dine	Iso leucine	Leu-cine	Ly-sine	Methi-onine	Phenyl alanine	Thre-onine	Val-ine
Justicia americana	3.0	1.1	2.5	4.3	2.8	0.9	2.8	2.3	2.9
Orontium aquaticum	3.2	1.0	2.3	4.3	2.6	0.8	2.8	2.3	2.6
Nymphaea odorata	2.8	1.1	2.0	3.8	2.7	0.7	2.2	1.9	2.6
Sagittaria latifolia	1.1	0.6	0.9	1.7	1.6	0.2	Trace	1.0	1.4
Alternanthera philoxeroides	2.1	1.1	1.5	1.9	1.5	0.6	Trace	1.6	1.8

Boyd, C.E., 1968a. Evaluation of some common aquatic weeds as possible feedstuffs. Hyacinth Control J., 7:26-7

The crude protein content of samples of 43 species of aquatic plants was determined and tannin analyses made. The author has summarized the results as follows:

Crude Protein Content (% DM)

More than 18%	12-18 %	Less than 12%
(a) containing less than 6% tannin		
Orontium aquaticum	Alternanthera philoxeroides	Myriophyllum heterophyllum
Jussiaea decurrens	Potamogeton diversifolius	Potamogeton nodosus
Elodea densa	Eichhornia crassipes	Polygonum sagittatum
Ceratophyllum demersum	Myriophyllum spicatum	Typha latifolia
Najas guadalupensis	Cabomba caroliniana	Nymphoides aquaticum
Justicia americana	Eleocharis acicularis	Hydrolea quadrivalvis
Nuphar advena	Spirogyra sp.	Hydrochloa carolinensis
Rhizoclonium sp.	Pithophora sp.	Pistia stratiotes
Hydrodictyon reticulatum	Chara sp.	
Sparganium americanum	Oedogonium sp	
Lyngbya sp.	Nitella sp.	
(b) containing more than 6% tannin		
- -	Nymphaea odorata	Potamogeton crispus
	Myriophyllum brasiliense	Hydrotrida caroliniana
	Brasenia schreberi	Polygonum hydropiperoides
	Saururus cernuus	P. pensylvanicum
	Nelumbo lutea	Jussiaea peruviana
		J. diffusa

Crude Protein Content (% fresh weight)

Species	%	Species	%
Justicia americana	3.4	Myriophyllum spicatum	1.3
Sagittaria latifolia	2.6	Ceratophyllum demersum	1.1
Sparganium americanum	2.5	Cabomba caroliniana	0.9
Orontium aquaticum	2.6	Vallisneria americana	0.8
Alternanthera philoxeroides	2.5	Eichhornia crassipes	1.1
Jussiaea decurrens	2.3	Pithophora sp.	2.5
Elodea canadensis	2.3	Chara sp.	1.5
Najas guadalupensis	1.7	Rhizoclonium sp.	1.1
Potamogeton diversifolius	2.2	Hydrodictyon reticulatum	0.9
Eleocharis acicularis	1.7	Spirogyra sp.	0.8
Nuphar advena	2.5	Nitella sp.	0.7

Boyd states that protein content declines rapidly with maturity. Therefore harvesting for fodder should be at maximum protein content related to total plant material. He adds that typical fresh forage crops have a protein content of 3-5%. Therefore to obtain comparable analyses aquatic plants would have to be partially dried.

Boyd, C.E., The nutritive value of three species of water weeds. Econ.Bot., 23:123-7 1969

This article gives analytical data on Eichhornia crassipes, Pistia stratiotes and Hydrilla sp. not included in the author's previous publications. Protein, amino acid and plant nutrient analyses are given.

Amino Acid Composition of Water Weeds

% Dry weight

Analysis	Eichhornia crassipes		Pistia stratiotes		Hydrilla sp.	
Crude protein	25.67	26.21	21.56	24.50	19.94	15.00
Actual protein[a]	19.35	19.55	15.75	19.50	16.60	10.57
Lysine[b]	1.13	1.30	1.13	1.30	1.01	0.43
Histidine[b]	0.41	0.43	0.31	0.47	0.32	0.18
Arginine[b]	1.12	1.24	0.52	1.15	0.97	0.49
Aspartic acid	2.82	2.64	2.20	1.90	1.90	1.33
Threonine[b]	0.96	0.98	0.79	0.98	0.83	0.49
Serine	0.88	0.95	0.80	0.97	0.91	0.59
Glutamic acid	2.39	2.46	2.11	2.61	1.98	1.25
Proline	0.88	0.97	0.75	1.00	0.82	0.51
Glycine	1.17	1.16	0.97	1.22	1.28	1.00
Alanine	1.33	1.37	1.10	1.39	1.20	0.68
Cystine	0.06	0.05	0.06	0.07	0.09	0.01
Valine[b]	1.20	1.13	1.01	1.21	0.98	0.66
Methionine[b]	0.37	0.34	0.24	0.38	0.34	0.23
Isoleucine[b]	1.01	0.99	0.81	1.03	0.80	0.56
Leucine[b]	1.75	1.77	1.43	1.82	1.49	1.01
Tyrosine	0.75	0.77	0.65	0.82	0.69	0.55
Phenylalanine[b]	1.12	1.00	0.87	1.18	0.99	0.62

[a] Sum of amino acids. Tryptophan analysis not obtained.
[b] Essential amino acids.

Fertilizer Units for Water Weeds

	Dry basis			Fresh basis		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Eichhornia crassipes	2.5	1.0	5.3	0.1	0.06	0.3
Pistia stratiotes	2.1	0.7	4.2	0.1	0.04	0.2
Hydrilla sp.	2.7	0.6	3.5	0.2	0.05	0.3

Analyses of freshly harvested plants:

Species	Water %	Dry matter %	Crude protein %
E. crassipes	94.1	5.9	0.94
P. stratiotes	94.1	5.9	0.78
Hydrilla sp.	92.0	8.0	1.37

Inorganic nutrient analyses (% DM):

Species	P	S	Ca	Mg	K
E. crassipes	0.43	0.33	1.0	1.1	4.4
P. stratiotes	0.30	0.55	2.4	1.0	3.5
Hydrilla sp.	0.28	0.39	4.5	0.9	2.9

Boyd, C.E., 1969a Production, mineral nutrient absorption and biochemical assimilation by Justicia americana and Alternanthera philoxeroides. Arch.Hydrobiol., 66(2):139-60

Detailed studies were made of the nutrient uptake and production of Justicia americana and Alternanthera philoxeroides. The author observes that J. americana, an emergent species, absorbs large amounts of nutrients, especially N and P, early in the season. He suggests that this could have important ecological significance because it would deplete the water of these nutrients before the optimum condition for phytoplankton growth can occur. Thus the phytoplankton population would be effectively reduced and so lessen competition for nutrients later in the season. He speculates that if this feature is also the case for other vascular plants it would explain why many shallow-water lakes consistently produce large crops of vascular plants and small crops of phytoplankton. Moreover, if only some species of angiosperms have this ability to absorb and store particular nutrients early in the season it might explain why such species typically occur in dense, relatively monospecific, stands. The plant having stored a surplus of nutrients can use them and translocate them to growing points when environmental conditions are optimum.

It was found that more than 50% of the total absorption of ash and macronutrients (other than Mg) occurred prior to the first sampling date (mid-May). Though the standing crop of dry matter increased until mid-July no net uptake of N, S or Ca occurred past mid-June. Mg content doubled between mid-May and mid-June. Samples were taken from Lake Ogletree, Alabama, U.S.A., and a drainage ditch.

J. americana Analysis (dry weight) and crop amounts (g/m^2) (Lake Ogletree):

Constituent	mid-May % DM	mid-May g/m^2	mid-June % DM	mid-June g/m^2	mid-July % DM	mid-July g/m^2	mid-August % DM	mid-August g/m^2
Ash	17.7	191.6	16.1	352.7	15.4	377.8	14.1	232.5
N	2.8	30.6	2.0	44.3	1.7	42.0	1.6	37.7
P	0.2	1.9	0.1	2.7	0.1	2.8	0.1	2.2
S	0.2	2.4	0.2	4.0	0.2	4.0	0.2	4.0
Ca	1.0	10.3	0.9	19.7	0.7	17.9	0.7	16.6
Mg	0.4	4.2	0.4	9.0	0.6	15.0	0.4	11.0
K	4.1	44.1	3.3	72.0	3.1	75.2	2.4	54.4
	ppm		ppm		ppm		ppm	
Fe	904	1.0	1 085	2.4	710	1.8	1 644	3.8
Mn	125	0.14	112	0.25	51	0.13	62	0.14
Zn	278	0.3	265	0.58	156	0.38	114	0.26
Cu	27	0.03	26	0.06	33	0.08	29	0.06
	%		%		%		%	
Ether extract	3.3	35.3	4.0	86.7	3.3	81.9	3.7	85.1
Cellulose	26.6	287.6	25.6	604.9	24.5	602.5	24.6	568.1
Amino acids and proteins (%)								
Lysine	0.6		0.5		0.4		0.4	
Histidine	0.3		0.2		0.2		0.2	
Arginine	0.6		0.5		0.4		0.4	
Aspartic acid	1.8		1.2		0.9		0.9	
Threonine	0.5		0.4		0.4		0.3	
Serine	0.5		0.5		0.5		0.4	
Glutamic acid	1.5		1.1		0.9		0.8	
Proline	0.5		0.4		0.4		0.3	
Glycine	0.6		0.5		0.4		0.4	
Alanine	0.7		0.5		0.4		0.4	
Cystine	0.01		0.01		0.02		0.01	
Valine	0.6		0.5		0.5		0.4	
Methionine	0.1		0.1		0.1		0.1	
Isoleucine	0.5		0.4		0.4		0.3	
Leucine	0.9		0.7		0.5		0.4	
Tyrosine	0.4		0.3		0.3		0.2	
Phenylalanine	0.6		0.4		0.3		0.3	
Crude protein	17.7		12.6		10.7		10.2	
True protein	10.8		7.9		7.0		5.9	

A. philoxeroides Analyses (dry weight) and crop amounts (g/m^2) (drainage ditch)

Constituent	8 May % DM	8 May g/m^2	4 June % DM	4 June g/m^2	10 July % DM	10 July g/m^2
Ash	13.8	52.8	14.7	123.8	11.1	88.3
N	3.5	13.5	2.9	21.1	2.3	18.0
P	0.4	1.4	0.3	2.7	0.4	3.1
S	0.4	1.4	0.3	2.4	0.2	1.9
Ca	0.6	2.4	0.5	4.4	0.7	5.4
Mg	0.6	2.3	0.5	4.4	0.4	3.2
K	5.9	22.4	5.2	43.7	3.0	24.5
Ether extract	4.8	18.5	4.2	35.0	3.1	24.4
Cellulose	21.9	83.4	24.1	203.0	21.8	173.6

Boyd points out that A. philoxeroides also has the apparent ability to absorb large quantities of mineral nutrients prior to the period of maximum dry matter production. Though this plant and J. americana are strong competitors, yet they tend, when present together, to form individual monospecific stands without substantial mutual invasion.

Boyd, C.E., 1970 Production, mineral accumulation and pigment concentrations in Typha latifolia and Scirpus americanus. Ecology, 51(2):285-90

Maximum shoot standing crop of Typha latifolia and Scirpus americanus was recorded as 684 g/m^2. Levels of nutrients and pigments declined in both species as the plants aged, as shown in the following table:

		T. latifolia			S. americanus		
	Unit	April	May	July	April	May	June
Ash	% DM	10.1	7.3	4.2	10.7	7.7	6.8
N	% DM	2.4	1.0	0.5	2.7	1.0	0.8
P	% DM	0.3	0.2	0.1	0.3	0.2	0.1
S	% DM	0.2	0.2	0.1	0.7	0.6	0.6
Ca	% DM	0.8	0.9	0.5	0.5	0.6	0.6
Mg	% DM	0.2	0.2	0.1	0.2	0.3	0.3
K	% DM	3.5	2.1	1.6	3.6	1.9	2.2
Na	% DM	0.2	0.3	0.2	0.1	0.2	0.1
Carotenoids	mg/g DM	4.6	4.0	0.5	4.2	3.6	3.2
Chlorophyll a	mg/g DM	4.0	2.8	0.6	3.8	2.2	2.1
Chlorophyll b	mg/g DM	0.7	0.8	0.1	1.1	0.4	0.5
Water	% fresh weight	89.2	-	69.5	85.5	-	77.0

Analysis (%) of nutrients in Typha seed heads:

N = 0.81; P = 0.23; S = 0.10; Ca = 0.25; Mg = 0.22; K = 2.41; Na = 0.07.

The most rapid uptake of several nutrients in both plants was found to occur earlier than maximum growth rates.

Boyd, C.E., 1970a Chemical analyses of some vascular aquatic plants. Arch.Hydrobiol., 67(1): 78-85

This paper contains analyses of various plants all collected from the same site (a 1 200-ha lake) in autumn.

The author draws attention to the wide interspecific differences in analysis from plants growing in water of the following chemical composition (ppm):

Alkalinity	19.21	K	1.61
NH_4 - N	0.09	Na	6.70
NO_3 - N	0.07	Fe	0.029
PO_4 - P	0.008	Mn	0.002
SO_4 - S	1.03	Zn	0.008
Ca	2.64	Cu	Trace
Mg	1.04		

Macronutrient Contents (% DM)

Species	P	S	Ca	Mg	K	Na
Submersed plants						
Myriophyllum heterophyllum	0.16	0.24	1.47	0.26	1.25	1.87
Ceratophyllum demersum	0.26	0.30	0.77	0.42	4.01	1.16
Najas guadalupensis	0.15	0.28	0.98	0.47	3.49	0.61
Eleocharis acicularis	0.24	0.28	0.53	0.33	2.86	0.54
Utricularia inflata	0.12	0.26	0.67	0.21	1.98	1.52
Potamogeton diversifolius	0.27	0.50	1.14	0.19	3.08	0.44
Floating-leafed plants						
Nymphaea odorata	0.18	0.14	1.06	0.14	1.28	1.35
Nuphar advena	0.40	0.32	1.08	0.27	1.88	1.47
Nelumbo lutea	0.19	0.16	1.56	0.23	2.27	0.28
Brasenia schreberi	0.14	0.11	1.79	0.26	0.99	0.66
Emergent plants						
Typha latifolia	0.14	0.15	0.76	0.15	2.65	0.28
Hydrocotyle sp.	0.18	0.16	1.85	0.47	1.73	0.98
Scirpus americanus	0.18	0.59	0.50	0.22	2.83	0.09
Juncus effusus	0.27	0.26	0.38	0.11	0.89	0.40
Panicum hemitonium	0.14	0.23	0.38	0.25	1.06	0.19
Eleocharis quadrangulata	0.10	0.15	0.20	0.10	1.81	0.12
Sagittaria latifolia	0.30	0.15	0.55	0.18	4.04	0.14
Pontederia cordata	0.24	0.22	0.96	0.15	2.58	0.83

Micronutrient Contents (ppm DM)

Species	Fe	Mn	Zn	Cu
Submersed plants				
Myriophyllum heterophyllum	2 000	473	54	44
Ceratophyllum demersum	1 053	486	100	30
Najas guadalupensis	712	201	48	48
Eleocharis acicularis	2 920	192	68	42
Utricularia inflata	2 112	480	108	47
Potamogeton diversifolius	1 240	160	60	36
Floating-leafed plants				
Nymphaea odorata	600	128	32	36
Nuphar advena	740	300	50	35
Nelumbo lutea	126	607	50	40
Brasenia schreberi	500	265	267	32
Emergent plants				
Typha latifolia	120	412	30	37
Hydrocotyle sp.	1 245	196	53	53
Panicum hemitonium	133	292	31	26
Eleocharis quadrangulata	560	120	45	20
Sagittaria latifolia	460	355	46	57
Pontederia cordata	200	970	67	60

Pigment Contents

Species	Chlorophyll a mg/g DM	Chlorophyll b mg/g DM	Carotenoid MSPU/g DM
Submersed plants			
Myriophyllum heterophyllum	7.7	2.2	9.2
Utricularia inflata	6.2	0.7	9.2
Najas guadalupensis	8.5	2.5	12.8
Potamogeton diversifolius	5.7	1.5	6.6
Floating-leafed plants			
Nymphaea odorata	3.4	0.4	5.2
Nuphar advena	3.9	0.8	5.8
Nelumbo lutea	3.6	0.8	5.3
Brasenia schreberi	3.3	0.1	4.8
Emergent plants			
Pontederia cordata	3.3	0.8	4.5
Hydrocotyle sp.	5.1	1.2	5.9
Typha latifolia	2.6	0.7	1.5
Juncus effusus	1.3	0.2	1.6
Scirpus americanus	2.3	0.4	3.4

Boyd, C.E., 1970b Losses of mineral nutrients during decomposition of Typha latifolia. Arch.Hydrobiol., 66(4):511-7

The author determined the nutrient content of shoots removed from the plant and retained in bags held submerged beneath the surface of a lake, or suspended just above it. The experiment began in mid-winter.

T. latifolia - in submerged bags

No. of days elapsed	% DM N	P	K	Ca	Mg	Na
0	0.9	0.07	1.01	1.1	0.14	0.38
20	1.2	0.04	0.02	0.7	0.05	0.04
40	1.0	0.05	0.03	0.7	0.04	0.04
64	1.4	0.06	0.02	0.6	0.03	0.02
95	1.5	0.06	0.03	0.7	0.04	0.04
125	1.4	0.06	0.04	0.5	0.04	0.04
155	1.1	0.06	0.04	0.5	0.03	0.04
180	0.9	0.06	0.04	0.5	0.03	0.04

The same general trends were evident, but at a slower rate, for the suspended material.

The author concludes that the initial increase of N was related to a build-up of microbial biomass. The rate of loss of N increased rapidly after 95 days and corresponded with the spring temperature increase. At the end of the experiment N losses corresponded to dry matter disappearance. Within the first 20 days leaching of nutrients resulted in the loss of most of the Na and K, 50% of the Ca and P, and 75% of the Mg. Thereafter nutrient losses were at about the same rate as dry matter degradation.

Data on nutrient loss of other plants (including terrestrials) as described in the literature, are reviewed.

Boyd, C.E., 1970c. Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ.Bot., 24:95-103

Yield of Eichhornia crassipes, Justicia americana, Alternanthera philoxeroides and Typha latifolia under continual culture:

Species	Standing crop t/ha DM	Maximum productivity g/m^2/day DM	Maximum yield g/m^2/day DM	Crude protein t/ha DM
E. crassipes	12.8	14.6	54.7	12.4
J. americana	24.6	31.1	113.5	14.3
A. philoxeroides	8.0	17.0	62.0	11.1
T. latifolia	15.3	52.6	192.0	16.4

Analyses of these plants are reviewed from the literature.

Boyd, C.E., 1970d. Amino acid, protein and caloric content of vascular aquatic macrophytes. Ecology, 51(5):902-6

Typha latifolia and other aquatic plants were analysed.

Protein levels in T. latifolia decreased from 10.5% (dry weight) in April to 3.2% in July. The proportion of each amino acid in the protein did not change appreciably. Caloric values increased from 4 160 to 4 552 cal/g during the vegetative period.

Protein content of T. latifolia from different sites ranged from 4.0 to 11.9%. When plants grow in the same site protein variations indicate interspecific variation in protein synthesis. Crude protein is a fairly accurate estimate of actual protein in aquatic macrophytes though it may usually overestimate actual protein content by 10-20 %.

Protein and caloric content of plants from Par Pond, near Aiken, South Carolina, U.S.A.:

Species	Protein % DM	Calories/g
Typha latifolia	4.0	4 262
Hydrotrida caroliniana	10.5	4 058
Brasenia schreberi	10.9	4 026
Utricularia inflata	11.4	4 023
Nelumbo lutea	12.1	4 227
Myriophyllum heterophyllum	13.5	3 961
Eleocaris acicularis	14.1	4 256
Najas guadalupensis	14.4	3 918
Nymphaea odorata	14.6	4 180
Ceratophyllum demersum	17.1	3 906
Nuphar advena	21.6	4 315
Mean ± S.E.	13.1 ± 1.3	4 103 ± 45
Coefficient of variation	33.39	3.62

Amino acid composition (%) of T. latifolia protein at different stages of maturity:

Amino acid	April	May	June	July
Lysine	6.3	5.3	4.8	5.8
Histidine	2.4	3.2	1.8	2.1
Arginine	5.9	5.6	4.6	8.1
Aspartic acid	12.9	10.5	10.8	10.9
Threonine	4.8	5.1	5.0	4.7
Serine	4.9	5.1	5.5	5.6
Glutamic acid	12.5	12.7	13.7	16.1
Proline	4.6	5.6	6.0	4.7
Glycine	6.0	5.9	6.3	6.5
Alanine	7.2	6.7	7.3	5.9
Cystine	0.1	0.1	0.0	0.0
Valine	5.9	6.3	6.5	5.9
Methionine	1.5	1.4	1.9	1.3
Isoleucine	5.5	5.5	5.9	5.0
Leucine	10.0	9.9	9.8	9.0
Tyrosine	3.7	3.7	3.9	3.0
Phenylalanine	5.7	6.0	6.2	5.6

Boyd, C.E., Leaf protein from aquatic plants. In IBP Handb., (20):44-9 1971

Reviewing literature on yields of aquatic plants the author cites the following:

(a) Floating species such as Eichhornia crassipes and Pistia stratiotes may have standing crops of 10 000 kg/ha and, because of vigorous growth might, under a continuous cropping system, yield up to 100 000 kg/ha. They have a high moisture content of 92-97% and contain 3-4% nitrogen. From water hyacinth (E. crassipes) only about 15% of the total N was recovered in leaf protein.

(b) Submerged species can produce standing crops up to 5 000 kg/ha, seldom more. They contain 90% or more water and N levels range from 2-4%. Less than 30% of the total N of several species was extractable as leaf protein.

(c) Species with floating leaves have comparatively small standing crops, e.g.

Nymphaea odorata	1 800 kg/ha
Brasenia schreberi	790 kg/ha
Nelumbo lutea	990 kg/ha

Water and N contents are similar to floating species.

(d) Emergent species, e.g. Typha latifolia, Arundo donax, Scirpus lacustris and Cyperus papyrus, may have standing crop yields of over 20 000 kg/ha.

Other yields recorded were:

Alternanthera philoxeroides standing crop: 8 000 kg/ha; protein: 480 kg/ha
Justicia americana standing crop: 25 000 kg/ha; protein: 590 kg/ha
Sagittaria latifolia protein: 362 kg/ha

The author points out that these values are as high as those reported for leaf protein yields of crop plants and emphasize the value of aquatic plants as a crop.

Boyd, C.E., 1974. 7. Utilization of aquatic plants. In Aquatic vegetation and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp. 107-14

Data on analyses of various aquatic plants are reviewed, typical standing crop yields given, and these figures are compared with a typical fodder crop (alfalfa).

Species	Analyses (% Dry weight) Ash	Crude protein	Ether extract	Cellu-lose	Standing crop DM t/ha
Submerged plants					
Nymphoides aquaticum	7.6	9.3	3.3	37.4	1.8
Potamogeton diversifolius	22.7	17.3	2.8	30.9	-
Najas guadalupensis	18.7	22.8	3.8	35.6	1.1
Ceratophyllum demersum	20.6	21.7	6.0	27.9	6.8
Hydrilla verticillata	27.1	18.0	3.5	32.1	-
Egeria densa	22.1	20.5	3.3	29.2	-
Floating-leaved plants					
Nelumbo lutea	10.4	13.7	5.2	23.6	1.0
Nuphar advena	6.5	20.6	6.2	23.9	0.8
Myriophyllum verticillatum	-	-	-	-	2.4
Floating plants					
Eichhornia crassipes	18.0	17.1	3.6	28.2	12.8
Pistia stratiotes	21.1	13.1	3.7	26.1	4.6
Emergent plants					
Typha latifolia	6.9	10.3	3.9	33.2	15.3
Justicia americana	17.4	22.9	3.4	25.9	7.1
Sagittaria latifolia	10.3	17.1	6.7	27.6	7.3
Alternanthera philoxeroides	13.9	15.6	2.7	21.3	7.4
Orontium aquaticum	14.1	19.8	7.8	23.9	2.4
Eleocharis quadrangulata	-	-	-	-	7.2
Pontederia cordata	-	-	-	-	7.2
Crop					
Alfalfa (lucerne) hay	8.6	18.6	2.6	23.7	4.5

The author points out that there are considerable variations in the concentrations of most chemical constituents in samples of an aquatic plant species and this makes it difficult to predict the usefulness of a particular stand of plants. Concentrations may vary twofold or more when plants are harvested at similar stages of maturity but from different sites. For example, crude protein values from Typha latifolia shoots from 29 sites ranged from 5.4 to 13.2% of the dry weight. Concentrations of various constituents also increase, or decrease, as plants mature. The crude protein content of dried shoots of Justicia americana (from the same population) decreased from 23% in May to 13% in September.

Submerged and floating plants usually had higher values for crude protein than emergent or floating-leaved plants.

Large standing crops are found in tall emergent plants and values of 10-20 tons of shoots/ha are sometimes found in species such as Typha latifolia, Schoenoplectus (Scirpus) validus, Saururus cernuus, Panicum hemitonium and Juncus effusus. However, depending on the stage of growth of the plants, emergent species which produce large standing crops of dry matter usually have a higher fibre content and a lower protein content than emergent species which produce lower standing crops of dry matter. Thus species such as Justicia americana, Alternanthera philoxeroides and Pontederia cordata are of higher quality as feeds, though they normally have shoot standing crops of 4-8 t/ha. Large floating plants may also have large standing crops, and values of dry matter above 10 t/ha are commonly encountered in Eichhornia crassipes. Other floating plants usually have standing crops below 5 t/ha. Submerged and floating-leaved plants normally have standing crops of shoots which range from 1-5 t/ha.

Tannins decrease the digestibility of protein. Concentrations of tannin of 10% and more have been found in Myriophyllum brasiliense, Cabomba caroliniana, Ludwigia peruviana, L. stolonifera, Brasenia schreberi and Nymphaea odorata.

Inorganic elements are found in aquatic plants at concentrations within the range of values reported for crop plants and deserve no special mention. However, submerged aquatic plants from hard water often have marl encrustations on external surfaces which greatly increase the proportion of inorganic to organic matter. Ash values of 25-50% of the dry weight are common. Such plants would be of low nutritive value but would be useful as a calcium supplement in diets of low calcium content.

Boyd, C.E. and R.D. Blackburn, Seasonal changes in the proximate composition of some
1970 common aquatic weeds. Hyacinth Control J., 8(2):42-4

The authors have recorded the protein content of seven common aquatic plants (Alternanthera philoxeroides, Vallisneria americana, Hydrilla verticillata, Nuphar advena, Najas guadalupensis, Pistia stratiotes and Eichhornia crassipes (water hyacinth). They found no increase in protein content of any of these species as summer progressed. In A. philoxeroides and N. advena there was a decline. They conclude that the protein content of emergent species declines with age. For submersed species protein content may remain static or fluctuate. When increases occur they are related to new growth.

Ash content in A. philoxeroides and V. americana declined with age, but in the others only fluctuated.

The paper gives analyses for each plant for each month from April to August inclusive. The means of these figures are given below:

Plant	% Dry matter	% Dry weight		
		Protein	Ether extract	Cellulose
A. philoxeroides	10.6	14.6	4.3	20.9
V. americana	9.7	21.1	2.7	30.0
H. verticillata	8.6	28.2	4.8	28.4
N. advena	9.3	11.1	5.6	24.5
N. guadalupensis	11.9	28.8	4.6	26.7
E. crassipes	6.7	19.8	4.7	23.4
P. stratiotes	6.9	21.8	6.3	22.6

The authors point out that analysis of the whole plant does not reveal the variation which often exists between the contents of different parts of the same plant. As an example they give the analysis of Justicia americana shoots:

	% Water content	% Dry weight: Crude protein	Ether extract	Ash
Aerial shoots	86.7	20.66	4.75	17.47
Entire shoots	84.7	12.62	3.95	16.07

Boyd, C.E. and L.W. Hess, Factors influencing shoot production and mineral nutrient
1970 levels in Typha latifolia. Ecology, 51(2):296-300

Analyses of Typha latifolia (means, % of dry weight):

Ash	6.75	Mg	0.16
C	45.91	K	2.38
N	1.37	Na	0.38
P	0.21	S	0.13
Ca	0.89		

Standing crop values ranged from 428-2 252 g/m^2 (average 951 g/m^2).

The authors comment on the variability of mineral nutrient content. Maximum values for N, P, Ca and K were 3-5 times as large as minimum levels. The greatest amounts of S and Na exceeded the smallest by 10 and 20 times, respectively.

Boyd, C.E. and E. Scarsbrook, Chemical composition of aquatic weeds. In Proceedings of
1975 the Symposium on water quality and management through biological control. Gainesville, University of Florida, pp. 144-50

The analyses of about 80 species of aquatic plants from 35 papers published in the U.S.A. since 1921 are reviewed. The data are given in five tables, and include dry matter content, ash, crude protein, ether extract and fibre, also the minerals P, S, Ca, Mg, K, Na, Fe, Mn, Zn and Cu. The amino acid content of 22 species appears in Table 4 and the caloric content of 41 species in Table 5. The numbers of samples are shown from which the mean figures are derived, together with reference to the papers from which the data originated. Much of the information is listed under the different papers cited herein.

The authors comment that the wide variation in composition between species and within species was not unexpected. These variations can be due to variations in sampling methods and methods of analyses by different authors as well as the variations in content within the same species when growing in different sites and at different stages of growth.

*Byers, M., Extraction of protein from the leaves of some plants growing in Ghana.
1961 J.Sci.Food Agric., 12:20-30

Analyses of three common aquatic plants:

	Dry matter % of leaf	N % of DM
Pistia stratiotes	5.69	1.71
Nymphaea lotus	10.0	3.14
Polygonum sp. (= senegalense?)	20.6	3.02

Caines, L.A., 1965 The phosphorous content of some aquatic macrophytes with special reference to seasonal fluctuations and applications of phosphate fertilizer. Hydrobiologia, 25:289-301

In studies of phosphorous content of various aquatic plants the analyses (whole plant) were:

	P Content (mg/g DM)
Carex rostrata	0.78
Eleogiton fluitans	1.52
Equisetum fluviatile	1.90
Littorella uniflora	2.47
Lobelia dortmanna	2.05
Myriophyllum alterniflorum	0.95
Potamogeton praelongus	1.58

The lake in which these plants were growing was later fertilized with calcium superphosphate (at 126 kg/ha). Only the last two species showed evidence of greater uptake. The analyses taken 14 days later were:

M. alterniflorum	P (mg/kg)	2.58
P. praelongus	P (mg/kg)	2.38

Analyses of the P content of two species of Myriophyllum, from two different lakes in Scotland, were made at intervals from spring to autumn (% dry weight):

	M. spicatum		M. alterniflorum (1957)	
Month	1954	1955	Entire plant	Growing tip
April	-	2.5	-	-
May	-	-	4.3	6.7
June	1.5	1.8	2.2	2.7
August	0.9	1.5	1.7	3.9
September	-	-	1.2	2.8
October	-	1.8	1.7	4.2
November	-	-	1.4	3.5
December	-	-	1.8	3.0

The author points out the seasonal variation in P content of the plants which he says is related to their growing, flowering and fruiting phases. He showed that the highest concentration was found in the growing tips.

Chalmers, M.I., 1968 Report to World Food Programme on a visit to Sudan. In Animal production WFP. Mission report on animal nutrition in Sudan. Study on the use of water hyacinths in ruminant animal feeding and also as a means of weed control. Rome, FAO, Acc.No. 02787-68-WS

Analysis of water hyacinth:

	% of Fresh weight		% of Oven-dried weight		
	Lamina & petiole 1/	Lamina only	Lamina	Petiole	Root
Dry matter	9.6	-	94.0	93.2	94.5
Organic matter	8.5	-	-	-	-
Crude protein	0.73	2.08	11.8	0.7	1.2
Total ash	1.1	-	-	-	-
Insoluble ash	0.08	-	-	-	-
Crude fibre	-	-	24.8	10.2	?
Fat	-	-	2.4	1.6	-

1/ Lamina is about 1/5th by weight of the fresh green material.

Comparison of the analysis of water hyacinth on a dry basis with an 'average' straw and an 'average' hay. Ash compared with English pasture species:

Part	Crude protein %	Crude fibre %	Fat %	Total ash %
Fresh lamina & petiole	7.8	-	-	11.6
Fresh lamina	21.7	-	-	-
Dried lamina	12.6	26.4	2.6	-
Dried petiole	0.75	10.9	1.7	-
Dried root	1.2	-	-	-
'Hays'	11.2	32.0	-	-
'Straws'	5.1	42.9	-	-
Legumes	-	-	-	8.8
Grasses	-	-	-	4.8
Herbs	-	-	-	9.6

The author concludes that water hyacinth has a high ash content and inadequate protein, which is found mainly in the lamina. The carbohydrate is mainly in the petiole.

Cifuentes, J. and L.O. Bagnall, 1976 Pressing characteristics of water hyacinth. J.Aquat. Plant Manage., 14:71-5

The paper gives details of water hyacinth analyses. Water content of the whole plant was 94.96% ± 0.38%.

Analysis of liquid pressed out of water hyacinth (at about 600 kPa about 70% of the water was expressed):

Sample	Dry matter (% wet)	Crude protein (% dry)
Liquid	1.1 ± 0.2	66.4 ± 12.8
Solid	9.6 ± 0.9	18.0 ± 0.9

*Day, F.W.F., Water hyacinth as a source of potash. Agric.Bull.Fed.Malay States, 1918 6(7/8):309-14

The paper describes in detail the manufacture of ash and compares the potassium content of the ash with that of various other plants, including trees and grasses. Detailed tables are given, from which the mean figures have been extracted:

Analysis of sun-dried plant

Water = 11.4%; organic matter = 61%; ash = 27.6%
Ash analysis (mean): K_2O = 15.3%; P_2O_5 = 2.8%; SO_3 = 13%

*Dirven, J.G.P., The protein content of Surinam roughages. Qual.Plant.Mater.Veg., 1965 12:172-84

Protein analyses of the dry matter of aquatic plants and grasses compared with indigenous and cultivated grasses:

Type of plant	Name	Protein % Average	Lowest	Highest
Aquatic plants	Eichhornia crassipes	12.5	-	-
	Ipomoea reptans	29.0	21.5	36.5
Indigenous aquatic plants	Echinochloa polystachya	14.3	9.6	18.9
	Hymenachne amplexicaulis	13.9	7.8	21.3
	Leersia hexandra	12.5	7.1	16.7
	Luziola spruceana	18.8	14.1	24.0
	Paspalum repens	28.7	-	-
Indigenous non-aquatic grasses	Axonopus compressus	11.0	8.3	14.3
	Eriochloa polystachya	7.5	5.6	10.3
	Paspalum conjugatum	8.0	4.2	12.2
Cultivated grasses	Digitaria decumbens	12.7	5.8	25.5
	Ischaemum aristatum	9.2	5.5	14.2
	I. timorense	7.5	5.1	10.7
	Brachiaria purpurascens	8.5	4.3	18.9
	Pennisetum purpureum	8.3	3.1	15.6
	Zea mays	7.2	3.3	12.9

Easley, J.F. and R.L. Shirley, Nutrient elements for livestock in aquatic plants. 1974 Hyacinth Control J., 12:82-5

Analyses of Hydrilla verticillata, Eichhornia crassipes, Ceratophyllum demersum, Potamogeton pectinatus, Vallisneria americana and Najas guadalupensis for their value as stock food showed that the elements K, Mg, Cu, Zn and Mn were present at a range of concentrations similar to those of land plants. Na, Fe and Ca were higher, while P tended to be lower. E. crassipes (water hyacinth), exceptionally, had a lower Ca concentration (only 2%) (see Chapter VII).

Fekete, A., D. Riemer and H.L. Motto, Removal of Rhizoclonium from a pond and its 1972 relationship to dissolved nutrients. Proc.Northeast.Weed Sci.Soc., 26:193-6

The paper gives details of studies of a filamentous alga, Rhizoclonium sp.
Analysis: N = 3.64 - 3.87%; P = 0.14 - 0.17%
Yield: 4 600 kg/ha dry weight.

*Finlow, R.S. and K. McLean, Water hyacinth and its value as a fertilizer. Calcutta,
1917 India, Govt. Printer, 16 p.

Analyses of water hyacinth:

(a) Fresh plant:

water	95.5%
organic matter	3.5% (including N = 0.04%)
ash	1.00% (including K_2O = 0.20%, P_2O_5 = 0.06%)

(b) Ash analysis:

K_2O	28.7%
Na_2O	1.8%
CaO	12.8%
Cl	21.0%
P_2O_5	7.0%

Hyacinth ash thus contains about 50% KCl.

(c) Comparison with Pistia stratiotes and cow dung at a common moisture content of 65%:

	N %	P_2O_5 %	K_2O %	Organic matter %
Water hyacinth	0.5	0.28	2.6	28
P. stratiotes	0.7	0.26	1.6	24
Cow dung	0.5	0.30	0.4	21

(d) Comparison between large plants growing in water courses in the city of Dacca and stunted plants in shallow water in red soil districts:

Dried hyacinth	Large plants %	Stunted plants %
Ash	30.6	29.8
SiO_2	20.7	49.4
K_2O	34.2	11.4
P_2O_5	8.2	1.4
CaO	8.4	7.8
Cl	20.4	5.7

*Fish, G.R. and G.M. Will, Fluctuations in the chemical composition of two lakeweeds
1966 from New Zealand. Weed Res., 6(4):346-9

Analyses (mean values) of Elodea canadensis and Lagarosiphon major:

	No. of samples	Water % wet wt.	Dry Weight % N	P	K	Mg
E. canadensis (Lake Okataina)	3	92.1	2.8	0.34	2.9	0.27
E. canadensis (Lake Rotorua)	7	93.1	4.48	0.75	3.8	0.32
L. major (Lake Rotorua)	12	90.3	3.92	0.50	2.6	0.68

The authors state that the data indicate that Lagarosiphon has a greater content of dry material than Elodea, a fact no doubt related to the more rigid and robust habit of the former. It also contained rather less potassium but much more magnesium than Elodea. Some seasonal variation appeared to occur in the mineral content of Elodea from Lake Okataina, which has a catchment largely of undisturbed native bush. The winter samples of plants from this lake had the highest content of N, P and K, but no seasonal variation was apparent in the analyses of samples from Lake Rotorua, probably because of the non-seasonal artificial eutrophy to which the lake is subjected.

Important differences were found between the Elodea samples from the two lakes. Those growing in Lake Okataina had lower contents of N, P and, in some cases, K. The clear water and low organic production that characterize this lake compared with Lake Rotorua support the view that the composition of Elodea reflects the quality of the water in which it grows. The present data suggest that Lagarosiphon probably reacts in a similar way.

Many aquatic plants, including Lagarosiphon and Elodea, are anchored to the bottom deposits of a lake or river by adventitious roots, but nutrients are probably absorbed mainly by leaves and stems in contact with the free water. Although the concentration of dissolved salts in the surrounding water will largely control the density and composition of these plants, the evidence indicated a difference in composition between species, even in the same lake, as well as seasonal changes. It follows that if these water weeds are to be exploited commercially, preliminary plant analyses are needed to determine the best species and season for harvesting.

Gortner, R.A., Lake vegetation as a possible source of forage. Science Wash., 80:531-3 1934

Analyses of a range of aquatic plants for ash, protein and fibre compared with typical forage crops are given. The author points out that, with the exception only of Chara (which is uncommon), lake vegetation is characterized by high ash and protein content and low fibre. He suggests that legume hays are the only common forages which approximate to the lake weeds in these constituents.

Analyses (% Dry weight, mean results)

Plant	Ash	Crude protein	Crude fibre
Myriophyllum spicatum	18.1	17.5	13.1
Potamogeton amplifolius	28.5	12.0	19.8
P. richardsonii	30.2	12.3	17.7
P. pectinatus	13.0	19.0	19.4
P. zosteraefolius	18.4	11.5	22.6
Najas flexilis	20.8	13.6	19.0
Elodea canadensis	27.9	12.1	16.2
Ceratophyllum demersum	18.9	15.5	16.7
Vallisneria spiralis	28.6	15.0	18.3
Heteranthera dubia	28.4	13.3	13.7
Nymphaea advena	8.0	17.0	13.8
Chara sp.	30.4	5.2	15.2
Crop			
Alfalfa (lucerne) hay	9.4	16.3	31.0
Cow-pea hay	13.0	21.4	24.9
Soy-bean hay	9.4	17.5	27.2

Gratch, H., 1968 Water hyacinth - a menace that could be turned to a blessing. In Handbook of utilization of aquatic plants, edited by E.C.S. Little. Rome, FAO, Plant Protection and Production Division, PL:CP/20:16

Water hyacinth analysis: Compost N = 2.05%; P_2O_5 = 1.1%; K_2O = 2.5%

Yield = about 100 t/acre (250 tonnes/ha)
Estimated area covered in India = 500 000 acres (200 000 ha).

Harper, H.J. and H.A. Daniel, 1935 Chemical composition of certain aquatic plants. Bot.Gaz., 96:186-9

The variation in N content of aquatic plants grown in different situations is discussed. Potamogeton foliosus and Typha latifolia were both low in N when growing in sandy soil and high in N on dark organic soil. The N and P content of the plants analysed were found to be higher than in common cultivated forage plants and weeds. The authors draw attention to the potentials of both species for "luxury consumption" of P by these plants from nutrient-rich situations. This is possibly the first reference to this attribute. The summarized, averaged, analyses of the aquatic plants are given below in comparison with the terrestrial plants.

(% Dry weight)

Species	N	P	Ca
Eleocharis sp.	1.4	0.13	0.6
Elodea canadensis	2.0	0.19	9.3
Jussiaea diffusa	1.6	0.28	1.1
Myriophyllum pinnatum	2.1	0.20	4.0
Nelumbo lutea	2.1	0.22	2.9
Potamogeton americanus	2.0	0.35	2.2
P. foliosus	2.0	0.28	2.4
P. pectinatus	2.0	0.16	3.0
Sagittaria cuneata	2.0	0.23	1.0
Typha latifolia	2.0	0.18	0.46
Algae:			
Spirogyra sp.	1.0	0.10	6.79
Nodularia spumigena	2.8	0.36	2.10
Weeds and grasses:			
Ambrosia artemisiaefolia	1.3	0.22	1.94
Andropogon furcatus	0.5	0.08	0.27
A. scoparius	0.6	0.07	0.27
Erigeron canadensis	1.8	0.27	0.98
Lactuca scariola	1.6	0.28	1.82
Polygonum pennsylvanicum	2.5	0.15	1.55
Sorghastrum nutans	0.8	0.08	0.29
Syntherisma sanguinalis	1.5	0.19	0.36

The high Ca content of Elodea was attributed to encrustations on the surface.

*Hossain, W., Investigation of water hyacinth as fodder. Agric.Pak., 10(4):513-8
1959

Water hyacinth compared with napier grass (%, dry matter basis):

	Crude protein	Crude fibre	N-free extract	Ether extract	Total ash
Water hyacinth	6.5	27.8	50.6	1.7	16.4
Napier grass	5.4	31.9	44.2	1.9	16.7

Ingvason, P.A., The golden sedges of Iceland. World Crops, 21(3):218-20
1969

Analysis of a semi-aquatic sedge, Carex lyngbei (local name 'gulstör') in comparison with a leading pasture grass, Poa pratensis (bluegrass):

	C. lyngbei	P. pratensis
	%	
Water	22.4	21.1
Crude protein	12.1	12.3
Ash	5.8	8.65
Cellulose	22.5	29.8
Pentosans	21.4	24.1
Carbohydrate & fat	35.6	22.9
Digestible protein	79.8	89.1
Fibre	-	-

Analytical work on Icelandic sedges which was done in Sweden about 60 years ago showed a crude protein content average of 10.2%, carbohydrates 45.5% and fibre 20.7%.

Knipling, E.B., S.H. West and W.T. Haller, Growth characteristics, yield potential and
1971 nutritive content of water hyacinths. Proc.Soil Crop Sci.Soc.Fla., 30:51-63

Water hyacinth analysis (% of dry matter):

N = 1.75; Ca = 3.06; P = 0.63; K = 3.07; Mg = 0.63

Optimum temperature for growth is stated as 28-30°C.

Koegel, R.G., et al., Increasing the efficiency of aquatic plant management through
1973 processing. Hyacinth Control J., 11:24-30

Analysis of Eurasian water milfoil, Myriophyllum spicatum:

Fresh		Dry	
Water	93.5%	Protein	20-25 %
		Crude fibre	10-12%
		Xanthophylls	650-1100 ppm

Lancaster, R.J., M.R. Coup and J.W. Hughes, Toxicity of arsenic present in lakeweed.
1971 N.Z.Vet.J., 19(7):141-5

Analysis of three species of aquatic weeds compared with good pasture:

	Water content %	% Dry weight N	P	K	Na	Ca	Mg	Ash
Elodea sp.	87.7	2.6	0.43	3.1	0.97	2.6	0.29	7.3
Lagarosiphon sp.	88.1	2.9	0.35	1.6	1.2	2.5	0.43	7.0
Lagarosiphon sp.	94.2	3.8	0.74	3.5	0.71	1.0	0.29	29.9
Ceratophyllum sp.	91.5	3.3	0.47	5.9	0.68	0.66	0.52	7.0
High quality pasture	85.0	3.5	0.4	3.0	0.3	0.8	0.2	10.0

The authors do not comment on the substantial differences in analysis between the two samples of Lagarosiphon - especially the high ash content of the second sample.

Lawrence, J.M. and W.W. Mixon, Comparative nutrient content of aquatic plants from
1970 different habitats. Proc.Annu.Meet.South.Weed Sci.Soc., 23:306-10

Analyses of Eichhornia crassipes (water hyacinth), Alternanthera philoxeroides (alligator weed) and Justicia americana (water willow) from different habitats containing a wide range of nutrients, and covering a period of four years, are recorded. The results, averaged and summarized below, reveal the wide range of N, P and K the plants can contain if growing in water fertilized to various degrees with these elements.

	Water habitat	% Dry weight N	P	K
E. crassipes	Raw sewage	2.20	0.38	3.83
	Agricultural pollution	2.55	0.42	4.4
	Unfertilized pools	1.11	0.16	2.15
A. philoxeroides	Raw sewage	3.19	0.27	4.74
	Agricultural pollution	1.76	0.14	4.23
	Unfertilized pools	0.88	0.08	0.99
J. americana	Raw sewage	3.25	0.21	2.65
	Agricultural pollution	3.20	0.34	4.20
	Unfertilized pools	1.00	0.23	1.12

The authors conclude that these results clearly demonstrate the variation in elemental composition of plants of the same species. They have shown how aquatic plants, when growing in water containing ample quantities of N, P and K, will exploit the situation by "luxury consumption" of these elements, far in excess of what they need for healthy growth. The plants growing in low N pools, for example, appeared just as healthy as those growing in water with high N from sewage. An extreme example was in K uptake by A. philoxeroides. In one case consumption was 20 times the content of plants grown in unfertilized pools (7.3% K compared with 0.36%).

Linn, J.G., et al., Nutritive value of dried or ensiled aquatic plants. 1. Chemical
1975 composition. J.Anim.Sci., 41(1):601-9

Analyses of 21 aquatic plants are tabulated and compared with alfalfa (lucerne) hay. All the analyses are on a dry matter basis.

Proximate Analyses of Aquatic Plants and Alfalfa Hay

Plant	Crude protein	Ash	Ether extract	Crude fibre	Nitrogen-free extract
	%	%	%	%	%
Alfalfa hay,	16.91	8.84	2.10	31.60	40.55
Anacharis canadenis	14.70	4.49	1.07	11.39	68.35
Calla palustris	13.93	1.28	4.37	17.40	63.02
Carex lacustris	8.63	.96	2.96	27.41	60.04
Carex stricta	9.94	.90	.89	29.41	58.86
Ceratophyllum demersum	17.00	2.18	1.51	15.20	64.11
Chara vulgaris	7.92	5.62	.12	7.65	77.56
Eleocharis smalli	5.78	1.64	1.09	27.03	64.46
Lemna minor	17.86	1.61	2.19	11.82	66.52
Myriophyllum exalbescens	12.28	1.67	.21	13.49	72.35
Nuphar variegatum	15.70	.96	2.46	23.13	57.75
Nymphaea tuberosa	19.88	.80	2.40	16.33	60.59
Potamogeton amplifolius	14.36	2.39	1.53	15.72	66.00
Potamogeton pectinatus	14.05	3.22	.09	15.64	67.00
Potamogeton richardsonii	11.20	2.62	1.13	19.11	65.94
Sagittaria cuneata	21.81	1.91	1.37	17.34	57.57
Sagittaria rigida	14.78	2.27	1.79	23.69	57.47
Sparganium eurycarpum	7.60	2.47	.71	20.57	68.65
Sparganium fluctuans	13.19	1.04	1.67	14.42	69.68
Typha angustifolia	6.92	.93	.98	27.49	63.68
Vallisneria americana	15.15	3.10	.97	27.32	53.46
Zizania aquatica	9.88	2.44	1.10	27.43	59.15

Mineral Contents of Aquatic Plants and Alfalfa Hay

Plant	Ca	P	K	Na	Mg	Fe	Mn	Mo
			%				ppm	
Alfalfa hay	1.64	.26	1.77	.16	.32	200	52	-
Anacharis canadensis	5.50	.02	1.09	.517	.560	10	128	9.4
Calla palustris	1.02	.60	3.19	.128	.298	1231	498	23.8
Carex lacustris	.32	.17	.72	.023	.138	522	203	10.1
Carex stricta	.28	.17	.52	.020	.140	861	185	15.2
Ceratophyllum demersum	2.46	.22	1.29	.336	.686	546	281	18.9
Chara vulgaris	.42	.19	.84	.176	.085	1586	329	32.6
Eleocharis smalli	1.95	.17	1.00	.759	.399	534	175	18.9
Lemna minor	2.58	.17	1.20	.755	.457	248	103	13.2
Myriophyllum exalbescens	.92	.26	1.35	.766	.205	243	190	9.7
Nuphar variegatum	.52	.23	1.62	.508	.151	583	115	10.2
Nymphaea tuberosa	2.76	.13	1.56	.165	.440	391	112	14.4
Potamogeton amplifolius	1.01	.83	2.91	.172	.232	1651	505	41.0
Potamogeton pectinatus	3.76	.34	1.99	.107	.200	1171	535	21.0
Potamogeton richardsonii	4.03	.17	1.33	.139	.500	218	109	11.6
Sagittaria cuneata	.78	.55	2.82	.391	.354	1904	161	28.2
Sagittaria rigida	.99	.31	1.82	.243	.432	2083	236	30.2
Sparganium eurycarpum	.59	.29	1.12	.097	.166	1056	435	29.6
Sparganium fluctuans	.77	.27	2.11	.397	.264	342	484	13.6
Typha angustifolia	.69	.17	.88	.117	.177	1647	502	23.6
Vallisneria americana	1.82	.16	3.75	.571	.298	323	176	12.8
Zizania aquatica	.93	.17	.62	.250	.205	2442	180	26.5

The authors comment that the ash values for the aquatic plants (averaging 2.1%) were lower than for alfalfa hay. The figures given relate only to the minerals within the plants and do not include any surface contamination by soil or crustaceans. Normally submerged plants are found to be higher in ash content than emergent plants because of such contaminations. They may also be inherently richer in minerals but generally lower in ether extractable material.

Crude fibre, averaging about 19.5%, was found to be lower for all aquatic plants than alfalfa hay, due probably to the lower need for structural strength by plants supported by water buoyancy.

Average contents of Ca, 1.6%, P, 0.27%, K and Mg were all similar to those of land forages, though as shown in the tables there was considerable variation between species.

Detailed analyses of neutral detergent fibre, acid detergent fibre content, acid detergent lignin, hemicellulose and cellulose content of all the 21 plants tabled above were again compared with alfalfa hay.

Linn, J.G. et al., 1975a Nutritive value of dried or ensiled aquatic plants. 2. Digestibility by sheep. J.Anim.Sci., 41(1):610-5

A set of analyses comparing Myriophyllum exalbescens with Potamogeton pectinatus and with alfalfa (lucerne) hay is given in this paper.

*Little, E.C.S. and I.E. Henson, 1967 The water content of some important tropical water weeds. PANS (C), 13(3):223-7

Analyses of water content of plants grown in the United Kingdom from specimens collected from different countries:

Plant	Origin	Water (% Fresh weight) Whole plant	Leaf blade	Petiole	Stem	Roots
Water hyacinth	Sudan (Nile)	91.7	88.1	93.9	92.4	86.7
	Congo River	91.6	87.1	93.3	93.0	88.7
	Nicaragua	91.5	86.5	93.4	93.8	85.6
Pistia stratiotes	Guyana	92.3	94.0	-	92.4	88.2
Salvinia auriculata (= molesta)	Lake Kariba	92.8	92.5	-	92.6	93.3

The water content of various fodder crops (%) is cited from Woodham, H.E. (1954):

Pasture grasses	Kale	Maize	Lucerne	Turnips
80.0	84.1	81.5	85.0	91.5

The authors state that their results suggest that a typical water content of floating aquatic plants is about 92%. This compares with 92% determined for a submerged water weed, Elodea, by Fish and Will (1966). Thus to obtain the same dry matter of plant material from water weeds about twice as much fresh material is needed as for lucerne, or 2.5 times that for pasture grasses.

*Loosli, J.K., et al., The digestibility of water hyacinth (Eichhornia crassipes) by
1954 silage by sheep. Philipp.Agric., 38(2-3):146-8

Water hyacinth (fresh) compared with water hyacinth silage (%):

	Water	Protein	Fat	Fibre	NFE	Ash
Fresh	92.2	1.0	0.26	1.92	3.67	0.93
Silage (mean of three)	89.9	1.0	0.15	2.0	5.06	1.92

Maciejewska-Potapczykowa, W., L. Konopska and E. Narzymska, Proteins in duckweed (Lemna
1970 minor). Acta Soc.Bot.Pol., 39(2):251-5

Analysis of Lemna minor showed that 16% of dry matter was protein. The amino acid composition was similar to that of hen egg protein.

Mackenthun, K.M., A review of algae, lakeweeds and nutrients. J.Water Pollut.Control
1962 Fed., 34:1077-85

The author reviews the literature of yield and nutrient contents of aquatic plants and plankton in the U.S.A. He cites Lake Mendota, Wisconsin, where the 0 to 1-m zone contained 1 800 kg/ha of submerged weeds on a dry weight basis, the 1- to 3-m zone 2 700 kg/ha, and the 3- to 7-m zone 1 450 kg/ha. On Lake Green, Wisconsin, the corresponding figures were 660 kg/ha, 2 200 kg/ha and 1 775 kg/ha. Analyses gave 12% dry matter, 1.8% N and 0.18% P. A typical nutrient content of all the plants in a lake would be: N, 36 kg/ha, and P, 3.6 kg/ha.

Plankton content of Lake Mendota was found to vary seasonally ranging from:

spring - 400 kg/ha summer - 140 kg/ha
autumn - 360 kg/ha winter - 110 kg/ha (dry weight).

A typical population could thus tie up about 36 kg/ha N and 3.6 kg/ha P.

Blue-green algae are 6.8% N (approx.) and 0.69% P. Thus an algal population could theoretically tie up about 17 kg/ha N and 1.7 kg/ha P. This is about half the quantity held by a normal submerged weed population.

Mackenthun, K.M., Nutrients and their relationship to weed and algal growths.
1971 Hyacinth Control J., 9(1):58-61

The author has searched the literature and from it abstracted the following figures:

Crop per Lake Weed Hectare

	Phytoplankton	Attached algae	Submerged vascular plants
Wet weight (kg)	1 120 - 4 000	2 240	15 700
Dry weight (kg)	112 - 400	224	2 000
% N (dry weight)	6.8	2.8	1.8
% P (dry weight)	0.69	0.14	0.18
N in crop (kg)	7.9 - 28	6.8	36
P in crop (kg)	0.8 - 2.8	3.4	3.6

Moore, A.W., Azolla: biology and agronomic significance. Bot.Rev., 35(1):17-34
1969

Reviewing the literature on Azolla spp. the author cites analyses from Japan as:

crude protein, 23.8%; crude fats, 4.4%; crude fibre, 9.5%; starch, 6.4%.

In a table of analyses from nine sources, including Australia, Japan, Indonesia and North Vietnam, the following is the range of the results given from A. pinnata and A. japonica:

	% Fresh weight	% Dry matter				
	Water	N	P	K	Ca	Mg
	92.8 - 93.6	3.37 - 4.75	0.12 - 0.95	0.88 - 6.52	0.30 - 2.49	0.25 - 0.41
Average	93.3	3.99	0.47	2.33	1.08	0.32

Yields of 50 t fresh weight/ha/year have been reported from Vietnam. From the U.S.A. a yield of 7 t of fresh Azolla in 3-4 months from 0.1 ha was reported. Assuming a moisture content of 93.3%, and with a dry matter content of 4% N, the author calculates that this represents a yield equivalent to 160 kg N/ha. From India a yield of Azolla on ponds from November to January of about 2 200 kg dry matter/ha was recorded, containing about 90 kg N/ha. In small plot experiments in Japan, having added superphosphate, a yield of 140 kg N/ha was recorded in a period of seven weeks.

Discussing these figures in relation to the known nitrogen-fixing capacity of Azolla (see Chapter IX), the author comments: "It is evident that Azolla can assimilate in 3-4 months 100-160 kg N/ha. It is likely that at least half of this N is derived from the atmosphere."

Mukhtar, A.M.S., A preliminary study on the chemical composition of water hyacinth
1967 (Eichhornia crassipes) in the Sudan. Sudan J.Vet.Sci.Anim.Husband., 8(2):
124-6

Analysis of water hyacinth on air-dry basis (%):

	Dry matter	Crude protein	Ether extract	Ash	Crude fibre	NFE
Shoot	92.8	5.3	0.67	1.5	22.0	63.3
Root	92.8	5.4	0.77	3.4	19.0	64.2
Whole plant	93.4	5.7	0.62	2.9	20.0	64.2

The author points out the similarity of analyses of the different parts of the plant except for the higher ash content of the roots.

Average yield was 310 tonnes/ha.

Nelson, W.J. and L.S. Palmer, Nutritive value and chemical composition of certain fresh-
1938 water plants of Minnesota. Tech.Bull.Min.Agric.Exp.Stn., (136):1-34

The authors review the literature on analyses of Elodea, Myriophyllum, Vallisneria and other species since 1904 and point out the variability of analyses recorded. They indicate the large quantities of potential forage represented by the water weeds in the lakes of Minnesota, which cover 5 600 sq. miles (1.45 million ha) with an

estimated annual yield of over 860 000 t of dry matter, containing at least 124 000 t of protein; this yield is independent of droughts which may be experienced by dry-land farming nearby.

A summary is given below of some of their analyses of three species compared with earlier work on the same species in a similar locality. This illustrates the variations that may be observed. The figures are also compared with analyses made for a common fodder crop, alfalfa (lucerne).

	% Dry weight					
	Elodea	Myriophyllum sp.		Vallisneria sp.		Alfalfa
	1/	1/	2/	1/	3/	4/
Ash	21.9	13.8	20.7	15.6	25.2	7.7
Crude protein	26.8	25.8	18.8	15.2	11.8	17.3
Crude fibre	15.4	14.1	15.0	15.8	14.0	35.6
SiO_2	6.3	2.9	2.0	1.1	5.5	0.1
P	0.6	0.4	0.6	0.2	0.2	0.2
S	0.3	0.4	-	0.4	-	0.8
Cl	0.6	1.3	1.6	2.0	1.3	0.6
Na	0.5	0.8	-	2.4	0.6	0.04
Mg	0.7	0.7	0.8	0.8	1.1	0.3
K	3.7	1.9	-	6.8	4.6	2.4
Ca	2.8	2.8	3.1	1.6	5.8	1.4
Mn	0.3	0.5	-	0.04	0.4	-
Fe	0.4	0.1	0.1	0.05	0.6	-
Dry matter % fresh	7.5	13.3	9.8	5.2	7.1	29.4

1/ W.J. Nelson and L.S. Palmer, 1938
2/ H.A. Scheutte and A.E. Hoffman, 1921
3/ H.A. Scheutte and H. Alder, 1927
4/ H.E. Woodman et al., 1933

Parra, J.V. and C.C. Hortenstine, Plant nutritional content of some Florida water
1974 hyacinths and response by pearl millet to incorporation of water hyacinths in three soil types. Hyacinth Control J., 12:85-90

The means of analyses of water hyacinth from 19 different locations are given below:

	% Dry weight	Standard deviation
Ash	19.2	3.2
C	34.9	5.9
N	1.61	0.50
P	0.31	0.18
K	3.81	1.30
Ca	1.66	0.53
Mg	0.56	0.14
Na	0.56	0.36
C/N ratio	23.3	7.0

	ppm Dry weight	Standard deviation
Al	2 568	2 668
Cu	9	8
Fe	2 772	3 765
Mn	286	147
Zn	58	42
Cr	0 to 35	-
Pb	0 to 20	-

The authors point out the high Al content which could be hazardous if the hyacinths were used to fertilize aluminium-sensitive crops. The high Fe content would be beneficial.

Parra, J.V. and C.C. Hortenstine, Response by pearl millet to soil incorporation of
1976 water hyacinths. J.Aquat.Plant Manage., 14:75-9

Water hyacinth analyses:

% Dry weight		ppm	
Ash	18.3	Cu	10
C	38.6	Zn	45
N	1.2	Fe	1 002
P	0.4	Mn	366
K	3.6	Al	1 244
Ca	2.4	Pb	10
Mg	0.8		
Na	0.5		
Cl	3.8		

Pirie, N.W., Weeds are not all bad. (Water hyacinths and other pests can also be good
1970 animal fodder). Ceres, 3(4):31-4

The nitrogen content of a range of aquatic plants is tabulated:

Popular name	Scientific name	N % dry matter
Alligator weed	Alternanthera philoxeroides	1.3-3.5
Coontail	Ceratophyllum demersum	2.7-3.0
Water hyacinth	Eichhornia crassipes	1.3-3.7
Water hyacinth (leaves only)	E. crassipes	5.0
Canadian pondweed	Elodea canadensis	2.2-6.3
Water bind-weed	Ipomoea reptans	4.6-5.8
Water willow	Justicia americana	1.6-3.8
Duck weed	Lemna minor	2.5-5.0
Milfoil	Myriophyllum spicatum	1.8-4.1
Reed	Phragmites communis	1.8
Water lettuce	Pistia stratiotes	1.7-3.9
Pondweed	Potamogeton sp.	1.1-3.5
Salvinia	Salvinia auriculata	0.8-1.8
Reed-mace	Typha sp.	0.5-2.4

The author estimates the annual yield of aquatic weeds at 5-10 t/ha.

Pirie, N.W. (Ed.), Leaf protein: its agronomy, preparation, quality and use. IBP
1971 Handb., (2):192 p.

Chapter 3 of the above Handbook, "A survey of other experiments on protein production", was written by the editor himself. Referring to weeds as a source of protein, he comments that aquatic weeds should be considered separately as a potential crop because each area of water tends to be dominated by a single species and the water often contains nutrients such as N, P and K sufficient to encourage luxuriant growth. Many analyses have been published which are often not accompanied by an adequate description of the physiological state of the material analysed. He cites the table, shown in the reference on p. 36, of representative analyses taken from many sources. He says that it shows the wide variation in N content that has been found for the same species. It also shows that, when harvested at suitable times, some water weeds contain more N than conventional crop plants.

He cites (p. 37) the following potential yield figures (kg/ha):

	Standing crop	Annual
Eichhornia crassipes	50 000	120 000
Pistia stratiotes	20 000	70 000
Ipomoea reptans	25 000	80 000

He adds (p. 38) figures for the N and protein content of the same species.

Species	Stage of growth	% DM on pulp	% N on DM of pulp	% N on DM of fibre	pH of extract	Total N as % of N in pulp	Protein N as % of N in pulp	% N on dry crude protein
E. crassipes	Flowering	8.0	3.3	3.2	-	12	6	7.6
P. stratiotes	Pre-flowering	6.2	1.8	1.5	6.9	24	18	6.0
I. reptans	Pre-flowering	9.9	3.35	2.9	5.4	32	25	9.8

Quimby, P.C. and E.L. Robinson, Calcium oxalate in alligator weed and silverhead. Proc.
1975 Annu.Meet.South.Weed Sci.Soc., 28:264-5 (Abstr.)

Calcium oxalate (insoluble) analyses (% dry weight) in different parts of two related plants:

Plant	Part: Node	Part: Internode
Alternanthera philoxeroides (alligator weed)	1.96	0.02
Philoxerus vermicularis (silverhead)	3.48	0.07

Terrestrial A. philoxeroides plants, fertilized with N at 448 kg/ha, contained 4.40% water soluble oxalate and 5.10% insoluble oxalate, compared with unfertilized plants which had 2.8% and 1.6%, respectively.

In comparison, nodes of A. philoxeroides from a eutrophic lake contained only 0.6% and 1.90% of soluble and insoluble oxalates, respectively.

Rao, K.V., A.K. Khandekar and D. Vaidyanadham, Uptake of fluoride by water hyacinth, 1973 Eichhornia crassipes. Indian J.Exp.Biol., 11(1):68-9

Analyses of different parts of water hyacinth (ppm dry weight):

Element	Lamina	Petiole	Base of petiole	Root
Ca	23 200	22 200	26 200	12 100
Mg	6 000	12 600	19 200	1 800
Na	17	96	22 100	46
K	2 830	9 999	32 500	1 665
Mn	366	828	462	828
Fe	652	232	1 257	6 000
Co	3	3	3	3
Ni	60	35	20	13
Ti	186	372	560	1 332
Cu	17	10	50	50
Pb	35	25	40	175
Zn	50	50	300	67
P	12	129	1 039	117
F	25	60	30	60

Ash on dry weight basis of whole plant = 13.5%.

Reay, P.F., The accumulation of arsenic from arsenic-rich natural waters by aquatic 1972 weeds. J.Appl.Ecol., 9(2):557-65

Analysis of arsenic content in various plants growing in arsenic-enriched water (geothermal) and low-arsenic (non-geothermal) water in New Zealand:

Species	Arsenic content (mg/kg dry weight) in geothermal water	in non-geothermal water
Ceratophyllum demersum	650	1.4
Lagarosiphon major	251	-
Elodea canadensis	307	3.0
Potamogeton sp.	178	<6
Lemna sp.	30	2.5
Nitella hookeri	182	13.0
Azolla rubra	-	<2
Compsopogon hookeri	550	-
Enteromorpha nana	20	-
Typha orientalis	8	-
Scirpus sp.	12	-

Reay points out that the arsenic concentrations in the various plants were influenced by the concentration of this element in the water and not by the amounts in river and lake bottoms. The Waikato river, receiving arsenic from geothermal discharges, contained 30-70 µg/litre. Marine plants may contain up to 60 mg As/kg (dry weight), though most contain 10-20 mg/kg. This reflects the lower arsenic content in the sea of 2-5 µg/litre. Reay draws attention to the relatively low arsenic content in the emergent aquatics T. orientalis and Scirpus sp. (monocotyledons) and the high concentration in a red alga, C. hookeri, compared with a green alga, E. nana.

Riemer, D.N. and S.J. Toth, A survey of the chemical composition of Potamogeton and
1969 Myriophyllum in New Jersey. Weed Sci., 17(2):219-23

The authors carried out detailed chemical analyses of several species of Potamogeton, Myriophyllum and other genera in the family Nymphaeaceae. Wide variability was observed both between species and within species. A table of means was given:

Element	Potamogeton spp.[1]	Myriophyllum spp.[2]
	% dry weight	% dry weight
Na	0.56	1.15
K	2.28	1.75
Ca	3.38	1.38
Mg	0.33	0.32
Fe	0.73	2.10
Mn	0.16	0.76
P	0.33	0.43
S	0.44	0.29
N	2.51	2.81
Cl	1.18	1.86
	ppm	ppm
Cu	33.9	35.0
Zn	82.9	379.0

[1] including P. amplifolius, P. crispus, P. natans, P. pulcher and P. pectinatus.

[2] including M. heterophyllum and M. spicatum.

Analyses were made of a range of plants growing within the same body of water, which confirmed the wide difference in uptake that can occur between different species. For example, Na ranged from 0.20% in P. pulcher to 2.12% in Cabomba caroliniana. The N content of P. pulcher was 1.87% while it was 3.30% of M. heterophyllum.

Riemer, D.N. and S.J. Toth, Chemical composition of five species of Nymphaeaceae.
1970 Weed Sci., 18(1):4-6

Chemical analyses were made of different parts (leaf blades, petioles, top growth) of Nuphar advena, Nymphaea odorata and N. tuberosa, Brasenia schreberi and Cabomba caroliniana. Mean analyses:

Element	N. advena	N. odorata	N. tuberosa	B. schreberi	C. caroliniana
			% dry weight		
Na	0.11	0.94	0.88	0.66	2.60
K	2.68	2.19	1.94	1.25	2.20
Ca	1.06	0.85	1.06	1.70	1.24
Mg	0.22	0.15	0.16	0.34	0.41
Fe	0.12	0.14	0.04	0.70	0.29
Mn	0.08	0.01	0.02	0.02	0.43
P	0.36	0.30	0.29	0.24	0.44
S	0.15	0.14	0.13	0.17	0.25
N	2.08	1.97	1.98	2.39	2.85
Cl	1.97	2.14	1.93	0.79	2.03
			ppm		
Cu	10.2	8.6	10.8	15.0	45.5
Zn	22.2	34.5	31.7	85.3	792.0

As in the analyses carried out by Riemer and Toth and tabulated in the reference above, variations within the different parts of the plant and between species ranged from low to high.

An interesting point of detail was the narrow range of Fe concentration, for N. advena, in leaf blade and petiole. This suggested to the authors that this species may not have the Fe precipitates on its surfaces which have been reported for some submerged species.

Riemer, D.N. and S.J. Toth, 1971 Nitrification of aquatic weed tissues in soil. Hyacinth Control J., 9(1):34-6

Nitrogen analyses of a range of aquatic plants compared with a fodder crop:

Scientific name	Common name	% N (dry wt.)
Myriophyllum heterophyllum	Water milfoil, broadleaf	3.51
Cabomba canadensis	Cabomba	2.52
Elodea canadensis	Elodea	3.12
Peltandra virginica	Arrow arum	3.63
Nuphar advena	Spatterdock (leaves)	5.65
N. advena	Spatterdock (petioles)	2.43
Utricularia sp.	Bladderwort	3.57
Sparganium sp.	Burreed	2.54
Potamogeton pulcher	Heartleaf pondweed	2.11
Pontederia cordata	Pickerelweed	2.03
Lemna minor	Duckweed	3.38
Phragmites communis	Common reed	1.97
Medicago sativa	Lucerne (alfalfa)	3.77

Siriwardene, J.A. de, S.S.E. Ranawana and G.A. Piyasena, 1970 Study of the feeding value of Salvinia auriculata for growing pigs. Trop.Agric., Colombo, 126(1):31-4

Analysis of Salvinia auriculata (= molesta) compared with a grass, Brachiaria brizantha:

	% Wet weight					
	Dry matter	Crude protein	Ether extract	Crude fibre	Ash	NFE
S. auriculata	22.8	1.8	0.6	7.7	1.5	11.2
B. brizantha	4.9	0.5	0.01	1.6	0.9	1.9

*Smetana, P., 1968 Water hyacinth compared with elephant grass. Extract from report to the Government of Burma, by P. Smetana, FAO Poultry Expert, Burma. In Handbook of utilization of aquatic plants, edited by E.C.S. Little. Rome, FAO, Plant Production and Protection Division, PL:CP/20:51

Analysis (% fresh weight) of water hyacinth, Eichhornia crassipes, compared with elephant grass, Pennisetum purpureum:

	Water	Crude protein	Fibre	Carotene (IU/100 g)
Water hyacinth	88	2.04	2.42	13 100
Elephant grass	84	3.07	4.13	16 705

These figures were later rearranged and converted to composition in grams/100 g dry matter, by W.W. Thomann, Poultry Specialist, FAO:

	Crude protein	Fibre	Carotene IU
Water hyacinth	17.0	20.2	109 000
Elephant grass	19.2	25.8	104 000

Steward, K.K., 1970 Nutrient removal potentials of various aquatic plants. Hyacinth Control J., 8(2):34-5

Some of the literature on analysis, including yields, of different types of aquatic plants is reviewed.

Species	Source	Analysis % DM N	Analysis % DM P	Annual yield DM tonnes/ha
Submerged plants				
Sagittaria subulata	U.S.A. (Florida)	4.0	0.4	23.2
Thalassia testudinum	Puerto Rico	4.0	0.4	33.5
Hydrilla verticillata	U.S.A. (Florida)	3.9	0.4	2.5
Myriophyllum exalbescens	U.S.A. (Wisconsin)	4.0	0.4	2.5
Emergent plants				
Typha latifolia	U.S.A.(Minnesota)	1.5	0.18	51.5
Cyperus papyrus	Tropics	1.5	0.15	83.5
Phragmites communis	Romania	1.5	0.15	32.5
Floating plants				
Eichhornia crassipes	U.S.A.(Louisiana)	4.0	0.4	36.8
E. crassipes	Subtropics	4.0	0.4	167.0

Steward points out the lower yields and hence nutrient content of submerged weeds, attributed to the less abundant supply of carbon dioxide and light to which they have access, compared to emergent or floating plants.

Sutton, D.L. and W.H. Ornes, 1975 Phosphorus removal from static sewage effluent using duckweed. J.Environ.Qual., 4(3):367-70

In the course of the experiments reported, analyses (% dry weight) of a mixed population of Lemna gibba and L. minor gave the following results:

crude protein = 10.6; P = 0.3.

Sy, Se Hiong, 1974 Mechanical management of aquatic vegetation. Ph.D. Thesis, Wisconsin Univ., U.S.A., 254 p. (Cited in Weed Abstr., 25(10):3023 (1976))

Analyses of Myriophyllum spicatum showed peak crude protein content only slightly lower than that of lucerne. Calcium and xanthophyll contents were high, and crude fibre low, in relation to forage crops.

Taylor, K.G. and R.C. Robbins, 1968 The amino acid composition of water hyacinth (Eichhornia crassipes) and its value as a protein supplement. Hyacinth Control J., 7:24-5

Protein and amino acid contents of water hyacinth were analysed.

Analysis (% Dry weight)

	Dry matter	Ash	N	Crude protein	Crude fibre	Ether extract	N-free extract
Leaves	15.8	14.7	1.7	10.7	17.0	2.7	54.7
Whole plant	8.9	-	1.5	9.6	-	-	-

Amino Acid Content: % of Water Hyacinth Crude Protein
(16 g N/100 g crude protein)

	%		%
Methionine	0.73	Arginine	2.98
Cystine	11.60	Histidine	1.90
Phenylanaline	4.72	Glycine	5.14
Tyrosine	2.98	Alanine	5.59
Threonine	4.32	Serine	3.85
Lysine	5.34	Aspartic acid	17.37
Isoleucine	4.32	Glutamic acid	9.29
Valine	0.27	Proline	4.73
Leucine	7.20		

The recovery of amino acids accounted for 92.3% of the total protein. Losses may be due to either incomplete hydrolysis or destruction of other amino acids, including tryptophan.

The lycine content was found to be in sufficient concentration to serve as an effective supplement to grain protein.

The amino acid analyses were taken from a plant containing 9.6% protein. Higher protein levels occurred in June and July with lower levels in May, August and September.

Young plants have a higher protein content than mature plants but produce a proportionally smaller yield.

Taylor, K.G., R.P. Bates and R.C. Robbins, 1971 Extraction of protein from water hyacinth. Hyacinth Control J., 9(1):20-2

Water hyacinth analyses showed water content was 94.6%, and crude protein content was 0.43% fresh weight.

Analyses (% dry weight) at different seasons for crude protein and fibre:

	Summer	Winter	Spring
Crude protein	4.7	5.8	9.2
Fibre	5.0	5.4	5.8

Telitchenko, M.M., G.V. Tsytsarin and Ye.L. Shirokova, Trace elements and algal "bloom". 1970 Hydrobiol.J., 6(6):1-6

The literature from U.S.S.R. on the trace element content of algae and diatoms is reviewed.

The needs of algae for various trace elements and the concentrations at which these elements can prove toxic were determined. During a "bloom" of algae (Aphanizomenon flos-aquae and Microcystis aeruginosa) the following range of trace element concentrations were determined in 1 kg of algae:

µg x 10^2	µg x 10	g
Mn	Ti, Ba, Cu	Sn, Ni, Cr, Pb

*Welch, P.S., Chemical composition of aquatic plants. In Limnology, by P.S. Welch. New 1935 York, McGraw Hill, pp.280-1

The author has condensed aquatic plant analyses taken from papers by Scheutte and Alder (1927) and Scheutte and Hoffman (1921).

Analyses (%)

Constituent	Clado-phora	Myrio-phyllum	Vallis-neria	Potamo-geton	Castalia odorata	Najas flexilis	Chara
Ash	26.53	20.72	25.18	11.42	11.21	19.16	41.22
Crude protein (N x 6.25)	18.19	18.75	11.80	8.02	17.38	11.62	4.50
Ether extract	2.00	2.44	0.73	0.91	2.54	1.63	0.76
Crude fibre	17.33	15.01	14.00	18.85	19.70	18.41	9.32
Pentosans	9.10	7.70	6.88	10.50	11.95	8.45	4.70
Nitrogen-free extract	26.85	35.38	41 41	50.30	37.22	40.23	39.50

Composition of the Ash (%)

Constituent	Clado-phora	Myrio-phyllum	Vallis-neria	Potamo-geton	Castalia odorata	Najas flexilis	Chara
SiO_2	7.08	1.96	5.45	0.78	0.32	1.89	0.83
Fe_2O_3	0.49	0.08	0.81	0.11	0.09	0.40	0.06
Al_2O_3	1.30	4.25	0.57	0.23	0.08	0.25	0.81
Mn_3O_4	0.75	Trace	0.52	0.08	0.09	0.05	0.08
CaO	3.35	4.28	8.16	3.38	1.89	8.56	37.82
MgO	1.62	1.34	1.87	1.38	0.75	1.61	1.19
Na_2O	-	-	0.81	0.26	1.20	1.05	0.35
K_2O	-	-	5.48	2.08	2.72	2.19	0.58
Cl	0.14	1.62	1.32	0.56	0.40	0.51	0.29
S	0.64	1.36	0.85	0.82	0.37	0.48	0.27
P	0.32	1.17	0.23	0.13	0.27	0.30	0.06
CO_3	-	-	-	-	-	-	39.00

*Williams, R.H., Salvinia auriculata Aubl.: the chemical eradication of a serious aquatic
1956 weed in Ceylon. Trop.Agric., 33(2):145-57

Analysis of Salvinia auriculata (= molesta):

Fresh weight % Water	Dry weight % Organic matter	Ash and sand	N	K_2O	P_2O_5	CaO
89.3	56.7	43.3	0.84	1.46	0.21	0.39

*Anon., Water hyacinth - a new use. Madras Agric.J., 38(1):27-8
1951

The estimated yield of water hyacinth per annum was 60 t/acre (150 tonnes/ha.)

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The reader who has studied the analytical data given in this chapter, especially if the original papers have also been consulted, will have noted the considerable variation in results between authors working on the same plants and also within the work of one author or team. Many workers have drawn attention to this and have reported how variations can also occur between plants of different age and when sampled at different times of the year. Yet throughout there seems to be a consistent finding that the analyses of water plants when taken on a dry matter basis do not differ substantially, in organic or inorganic content, from typical crop and other plants growing on dry land.

A characteristic and different feature of some water plants which can complicate analytical results is the encrustation of lime, iron and other minerals on the surfaces of submerged plants as a physical deposit, or as a consequence of micro-organisms living on the plant surface. Rooted aquatic plants may, during harvesting, be brought to the surface with bottom mud entangled in their roots, again complicating analyses.

However, the main analytical difference between water and land plants is the high water content of the aquatics, because they are necessarily harvested wet, and have a higher internal water content. It is the inconvenience, and extra cost involved, of this feature which is a main limiting factor in the harvesting and utilization of aquatic plants.

More work to overcome this problem is needed to supplement the use of solar heat for drying, and mechanical pressing of water from the plant tissues. Both are included in some of the foregoing papers. However, in using any mechanical method of extracting water note should be taken of observations by N.W. Pirie (1971) (p.135) that "it is difficult to press fluid out of an undamaged leaf", and, if the plant is pulped before pressing, "protein is lost to an extent approximately proportional to the extent to which water is being removed."

This harvesting problem is therefore not simple, but it must be faced and solved for widespread aquatic weed harvesting to be accepted (see Chapter IV).

Paddy growing on floating island in Rawa Pening lake,
Central Java, Indonesia

Cyperus papyrus, Salvinia sp. and Pistia sp.
in Lake Naivasha, Kenya

IV. METHODS OF HARVESTING

Plants growing in water require special techniques to harvest them and transport them to the bank for whatever processing is needed for their ultimate utilization or disposal. The material is wet, it may be muddy, and in some circumstances may harbour dangerous micro-organisms or even animals.

The different growth habits of water plants - submerged, rooted with floating leaves, wholly floating, or tough rank plants emerging from shallow water - can add to harvesting difficulties. Each type of plant needs different tools and a different method of attack.

The literature in the main describes various mechanical techniques which have been evolved, mostly in the U.S.A. Yet for most of the people living in developing countries, to whom aquatic weeds may be a dangerous nuisance as well as a potential crop, harvesting must be done by hand from the bank, or by using small boats, and with conventional or specially designed hand tools. The literature on this aspect is sparse and reflects the needs and opportunities for simple technical advance in manual harvesting equipment.

An alternative approach is to introduce suitable animals which do the harvesting by eating the plants and then, at suitable intervals, to harvest the animals. There is an extensive literature on the use of fish, but a variety of other animals, including livestock, offer possibilities.

Hand and mechanical harvesting methods are considered separately in this chapter, and the use of aquatic plants as food for livestock in Chapter VII.

Harvesting of weeds can be rapid and efficient. It is a form of biological control by man. Other forms of biological control - by fish, snails or other animals - all take direct management of the situation out of man's hands. Robson (1974, p. 72) makes the same point: "Being wholly controlled by man, both cutting and dredging permit him to exert the maximum control over the amount of weed removed within the limitations of the machine used, in contrast to the indirect and less determinate effects of herbicides and biological control agents. Because of this, cutting especially has certain advantages over these other methods of weed control. Also cutting and removal of the plant material has the advantage of providing an opportunity for the utilization of the vegetation."

Fox and Prentice (1975) have reviewed harvesting aquatic weeds from lakes and the culture and removal of macrophytes. They contend that large-scale methods of removal in natural lakes are inefficient and expensive. The costs would have to be justified in terms of increased recreational value, not nutrient removal. (From Weed Abstracts)

Methods of surveying aquatic plants from the air by photography have been described by Benton and Newman (1976) and Edwards and Brown (1960).

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1. Hand Harvesting

Boyd, C.E., 1974. Utilization of aquatic plants. In Aquatic vegetation and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp.107-14

Large floating plants such as Eichhornia crassipes and Pistia stratiotes can be lifted from the water by hand or with a hay fork. Smaller floating plants such as Lemna or Azolla can best be removed with small mesh seines or dip nets. Submerged plants can be harvested by pulling rakes through the underwater meadows. Emergent and floating-leaved plants can be cut at the desired height with knives or, in areas with loose bottom soil, pulled from the substrate by hand. One man can harvest 1 500 kg or more of fresh weight of plants per day from moderately dense stands of most species.

*Hora, S.L., 1951. The water hyacinth problem and pig farming. Sci.Cult., 17(6):231-2

The daily harvesting of water hyacinth from ponds to feed pigs is referred to in this article.

Kamal, I.A. and E.C.S. Little, 1970. The potential utilization of water hyacinth for horticulture in the Sudan. PANS, 16(3):488-96

The authors describe and illustrate various simple items of equipment suggested for the use of workers collecting water hyacinth floating past on the river Nile. The project was supported by the World Food Programme and its objective was to encourage collection of the hyacinth both to help clear the weed from the river and to put it to use.

Methods tested included a boom made of floating drums linked together by wire and anchored at an angle to the bank to deflect clumps moving with the current towards the bank. Grapnels on long handles were tested as a means of extending the reach of a person working from the bank, as workers were reluctant to stand in the water because occasional snakes were found hiding in the weed. Simple metal hooks, similar to those used by wharf labourers, were found effective against the hazard of cercareae of bilharzia, or liver fluke organisms, and also enabled heavier loads to be carried with less fatigue. The methods are illustrated.

The wet condition of water weeds and the high water content of the plants are difficulties of harvesting frequently referred to by writers. In the Sudan, where solar radiation is high and accompanied by low humidity, conditions are good for drying plant material. The authors carried out experiments measuring the rate of drying of weighed samples of freshly collected water hyacinth, and concluded that a reduction in weight of the freshly harvested plant to about 25% of its original weight could be obtained 2 to 3 days after being spread in the sun.

Little, E.C.S., The floating islands of Rawa Pening. PANS, 15(2):147-53
1969

A lake in Central Java, Indonesia, clogged with floating islands of plants bound together with water hyacinth is described, with illustrations. The local people have devised an ingenious system of cutting suitable sized portions off these islands with long saws. The pieces are then assembled into rafts, about 70 m long x 6 m wide, by binding them together with thin strips of bamboo. The workers, using long poles, can push the islands several kilometres across the lake. Canoes placed on the islands give a firm stance to the polers. The mass of vegetation is usually discharged to waste over the spillway in a surge of released water after opening the sluice gates of the lake. Consideration was being given, instead, to utilizing all this material for agriculture. This would only be practicable after a proposed dyke had been built round the lake which would provide convenient points at which the material could be lifted out and deposited on dry ground.

Little, E.C.S., From water weeds to milk. (Letter) PANS, 16(1):198-9
1970

The author describes how an emergent sedge, Cyperus digitatus, could be hand-cut from the margins of a lake for chopping up and feeding to dairy cows.

Robson, T.O., 6. Control of aquatic weeds. 6.1. Mechanical control. In Aquatic vegeta-
1974 tion and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp.72-84

A description is given of the traditional tools used in Europe for centuries for hand-cutting of water weeds, which have evolved from agricultural implements: scythes, sickles and grass hooks, rakes and forks, chain scythes and chain knives.

U.S. National Academy of Sciences, National Research Council, Making aquatic weeds useful:
1976 some perspectives for developing countries. Washington, D.C., Agency for International Development, 175 p.

This book illustrates (p.68) how hand harvesting may supply enough feed or soil amendment for small farms.

Sawing an island of aquatic plants in Rawa Pening lake,
Central Java, Indonesia

Poling islands to the spillway in Rawa Pening lake,
Central Java, Indonesia

"Necklace" boom of floating drums anchored to the bank of the Nile river at Malakal, Sudan, to collect water hyacinth

Simple hooks used to carry clumps of wet water hyacinth from the bank of the Nile river in the Sudan

2. Mechanical Harvesting

Bates, R.P. and J.F. Hentges, Aquatic weeds - eradicate or cultivate? Econ.Bot., 30(1): 1976 39-50

The authors review the literature from the U.S.A. on harvesting and note the wide range of output and costs which have been recorded. They point out that these costs tend to make crops of aquatic weeds more expensive than ordinary low value crops. Harvesting may also be much more expensive than chemical weed control. It is the transport and disposal of the large quantities of weed that imposes a serious economic limitation on the method. Harvesting becomes worth while when aquatic weeds, for example water hyacinth, are cultivated as a means of removing nutrients from polluted water.

Blanchard, J., Winter Parks' lake weed management program. Hyacinth Control J., 7:30-1 1968

Mechanical harvesting of lake weeds, including Eichhornia crassipes (water hyacinth) Vallisneria americana (valisneria) and Hydrilla verticillata (Florida elodea), has been carried out with machines known as "Aquatic Scavengers". These boats combine both cutting and carrying the weeds. They can cut normally to a depth of 1.5 m if necessary. To deliver the collected weed on shore the conveyor is run in the opposite direction. Each unit can remove 100 t of Hydrilla, or 140 t of Vallisneria, each week. One unit was programmed to work in shallow water near the shore and the other out in deeper water.

Mechanical removal has been criticized, but the author believes that it is justified because of its psychological and practical effects. The expenditure of public money in its operation removes a public nuisance. Also it is no more harmful, in spreading cut weeds through the water, than the action of many boat propellors and the activities of birds. In removing the weeds from the lake they are not left to repropagate by seeding or, in the case of Hydrilla, by turions. Best results in controlling the weeds are obtained by a suitable combination of mechanical harvesting and the use of herbicides.

Boyd, C.E., Fresh water plants: a potential source of protein. Econ.Bot., 22:359-68 1968

The author comments that aquatic plants present unique problems of harvesting and processing. Quite different approaches should be taken by developing tropical countries compared with technologically advanced countries. Most tropical areas have cheap manual labour and the plants could be harvested by hand, but in the U.S.A. labour is so expensive that the plants must be harvested mechanically. The machines needed for this require considerable capital outlay and are costly to operate. In most areas weather conditions are too unstable to permit air drying, so mechanical driers would have to be developed. Most aquatic plants contain 2-4 times less dry matter than forages, so drying also would be very expensive. For example, to obtain 1 ton of dry Elodea canadensis or Eichhornia crassipes 14 and 20 t of wet material, respectively, would have to be processed. This excessive moisture content would prohibit transportation to a central processing plant so drying would have to be done on a barge or by a portable unit located on the shore. An operation as outlined above would have to be in almost continuous use and only very large plant stands could be exploited. So, based on this simple assessment of the problems of harvesting and drying, it appears very doubtful that aquatic plants have direct commercial possibility.

N.B. Boyd (1974, p.107) reinforced this view, commenting on Bailey (1965): "... the cost of harvesting and processing the plants by mechanical techniques has prohibited commercial exploitation."

Bruhn, H.D., R.G. Koegel and D.F. Livermore, Utilization of aquatic vegetation. Paper 1975 presented to the Annual Meeting of the Northern Atlantic Region of the American Society of Agricultural Engineers, New York, 13 p.

Discussing the merits of harvesting aquatic weeds the authors consider that the value of the weeds, in terms of the various uses to which they may be put, could only recover about 10% of the costs of harvesting them. Therefore they point out the need for harvesting to be made cheaper if there is any prospect of aquatic weeds being profitable as a crop. (From Weed Abstracts)

Bryant, C.B., You need weeds. Proc.Annu.Meet.South.Weed Sci.Soc., 23:301-5 1970

The author claims that the traditional means of removing lake weeds by labourers using long-handled rakes is a thing of the past. He describes the modern mechanical approach to harvesting as the means by which excessive weed growth can be efficiently removed, ensuring that the ecology of the lake is not unduly disturbed.

Harvesting also prevents the inevitable algal blooms which follow destroying weeds by herbicide or cutting weeds and then leaving the plants in the water to rot. Harvesting equipment designed by Aquamarine Corporation is described in detail, and Bryant contends that an aquatic weed harvester should be propelled by paddle wheels so that it can operate in shallow water (down to 30 cm depth). Paddles also enable the craft to turn on its axis and thus manoeuvre in confined places.

The author suggests that harvesting cannot be looked at as the last and most expensive resort. It is the most promising method of aquatic weed control and deserves research into costs and effectiveness. He claims that control of weeds by mechanical harvesting may be as low as 20% of the cost of chemical methods.

Bryant, C.B., Aquatic weed harvesting - effect and costs. Hyacinth Control J., 8(2):37-9 1970a

Illustrations are given of the H-650 AQUA-TRIO Harvester, the T-650 AQUA-TRIO transport and the S-650 AQUA-TRIO Shore Conveyor. An analysis is given of the results of trials with the equipment harvesting 20 acres (8 ha) of Hydrilla verticillata in Lake Maitland, Florida, U.S.A. The amount of weed harvested was about 300 t, averaging 2.5 t per load. The job took 170 man hours. Costs were US.S$620.00 for a 40-hour week, yielding 216 tons. This figure was arrived at as follows:

Item	Weekly cost (US$)
AQUA-TRIO set, initial cost $44 000 [1/])	
Dump truck, initial cost $3 500 [1/])	100.00
Interest at 10% on $47 500	100.00
Labour - 3 men at $8/hr for 40 hours	320.00
Maintenance and running costs	100.00
Total	620.00

[1/] Depreciation calculated on 10-yr lifetime

The rate of harvesting day by day throughout the period of the operation is also tabulated. The figures show a fairly regular progress of efficiency up to a maximum of 9.3 t per 3-man crew per hour.

A later operation, using 2 sets of AQUA-TRIOs on a river, resulted in 12 t of weed being harvested by each crew per hour. Bryant concludes that yield is related to the efficiency of the crew, which improves with experience. He also points out that before extrapolating these costs onto any other waters or weed infestations adjustments must be made to allow for changes in labour rates, weight of harvested weed, average weight of unharvested weeds per acre of lake, distance of weeds to shore conveyor site, dump truck haul distance and design of harvesting equipment.

Bryant, C.B., Control of aquatic weeds by mechanical harvesting. PANS, 19(4):601-6 1973

Continuing his case for harvesting of aquatic weeds instead of destroying them with chemicals, the author states: "Any method of control which does not remove nutrients from the water does not solve the problem. When weeds are killed they fall to the bottom and decay. During the decaying process they use up a portion of the oxygen in the water and deny that oxygen to the many forms of animal life in the water, thus endangering them or even suffocating them. ... Since mechanical harvesting on a large scale is relatively new, little work has been done to document its long-term benefits. But there seems to be little or nothing to indicate that it is harmful."

Bryant lists the criteria required for efficient aquatic harvesting machinery, then goes on to show how the AQUA-TRIO equipment designed by his organization meets them. The equipment consists of a harvester 11.99 m long with a cutter bar at the forward end, the transporter, 9.14 m long, which takes the weeds from the harvester, and a two-part shore conveyor which can take the weeds from either harvester or the transporter and then lift them into a truck. The criteria given are:

(a) shallow water operation;
(b) to cut weeds from 0-1.5 m deep and extract all cuttings from the water into the hold;
(c) capable of hitting unseen immovable objects at high speed without serious damage;
(d) maximum load capacity with minimum empty harvester weight;
(e) fast off-loading capability;
(f) all controls powered;
(g) capability to transport large quantities of weed to shore after harvesting in minimum time and with minimum manpower;
(h) loading into truck capability;
(i) able to be installed in many varied access points at low cost and still operate at top efficiency;
(j) towable by road at a maximum width of 2.44 m;
(k) launchable via a ramp into the water or, alternatively, by crane.

Much work has yet to be done to make the costs of harvesting equipment decrease to the the level of, say, farm equipment. High production can easily result in these lower costs. Toward this end much research is being financed by the U.S. Department of Interior, Office of Water Resources Research. Among the areas under research are higher harvesting speeds and weed chopping, pressing and de-watering schemes. If end products from the harvested weeds can be developed, a great step toward financing weed harvesting can be made.

Bryant adds that the equipment described has been used in nine states of the U.S.A., four provinces of Canada, and in Scotland, Iceland and Braxil. The paper has four illustrations.

Bryant, C.B., Aquatic weed harvesting, costs and equipment - 1972. Hyacinth Control J., 1974 12:53-5

The author tabulates harvesting operation costs for various locations and states that the cost of harvesting aquatic weeds seems to be diminishing as equipment design improves. The selection of equipment is broadening and new developments in the near future will further reduce costs. Thus harvesting should be increasingly used as a method of controlling growth of aquatic vegetation. Costs can be further drastically reduced if work can be continued for longer hours, including into the night, instead of just for the usual working day. Harvesters can be, and have been, fitted with lights to make night operation possible.

It is estimated that since 1945, 50-75 aquatic weed harvesters have been produced commercially. As most of the work is against submerged weeds the method has developed into a standard system. A powered barge has underwater cutters mounted in front of an inclined porous conveyor, with a holding area for the harvested weeds; there is a handling or transporting system to shore.

The bulk of harvesting design and innovations appear to have been centred in Wisconsin, U.S.A. Bryant refers to Grinwald (1968) as being the originator of mechanical harvesting machinery (see p.58). A succession of enterprises has resulted in the Aquamarine Corporation, with 25 harvesters operating in 1972.

Cifuentes, J. and L.O. Bagnall, Pressing characteristics of water hyacinth. J.Aquat. 1976 Plant Manage., 14:71-5

In order to facilitate harvesting of aquatic weeds reduction in the high water content is desirable. Using water hyacinth the authors investigated the effectiveness of a screw press in expressing water from the fresh plant. The plant had to be chopped for worth-while results. The smaller the size of the particle the faster the process. Increasing pressure up to 600 kPa increased juice extraction but higher pressure did not remove much more juice. If the cake was agitated between additional pressings, expression was increased by 12-20%. About 70% of the water was expressed from water hyacinth with an energy input of less than 100 J/kg of water expressed, but the energy required increased rapidly as more water was removed. The optimum expression time was about 40 seconds.

Deutsch, A. (Ed.), Some equipment for mechanical control of aquatic weeds. Rep.Int.Plant 1974 Prot.Cent.Ore.State Univ., (74-2):18 p.

A number of firms throughout the world construct and market specialized equipment for cutting, harvesting or otherwise mechanically controlling aquatic weeds. Some of these units are briefly described and addresses of the firms involved are given in this paper. The information represents most of those firms suggested by experts in aquatic weed control from a number of countries. The equipment is designed, with a few exceptions, to operate on the water surface. The text is divided into sections on aquatic weed cutters and rakes, other equipment (including prototypes), and a list of companies.

Many of the illustrations show operators working without safety equipment (life jackets, etc.) and some belt and drive shafts are without shielding. The author points out the need for adequate safety gear to protect machinery operators.

The following machines and equipment are illustrated and described:

(a) Airlec Industries Inc. (Madison, Wisconsin, U.S.A.)

WC10 Aquatic weed cutter and rake. The cutter is U-shaped, 107 cm wide and can cut to 107 cm deep. It is powered by a 2-cycle, 3-h.p. engine. The equipment weighs 99 kg and may be mounted on the bows of most boats of 4.5 m or longer. The same frame can carry the rake which is 2.8 m wide. Operation may be at 5-10 km/h depending on weed density. The unit requires two operators, one to steer the boat by the outboard motor.

(b) American Waterweed Harvesting Co. (Shreveport, Louisiana, U.S.A.)

Waterbug. The unit, 6.1 m long and 1.5 m wide, 13 cm draft, has two polyethylene pontoons supporting a metal platform. It is propelled by a 1.2-m diameter steerable (360°) air fan powered by an 8 h.p. engine, giving a speed of 8 km/hr. The cutter consists of two vertical blades and a 2.4-m horizontal blade. A 3.7-m wide blade is also available. Cutting can be to a depth of 1.2 m. The unit is operated by one man.

Waterweed harvester. This is a large unit 21 m long, 5.5 m wide, and draws 30.5 cm. It is propelled by a propane-burning engine (6.4-litre) powering the rear mounted propulsion fan, and an electric generator or a hydraulic pump. There is a powered conveyor at the bows, which has, on its leading edge, a 4.9-m wide sickle bar cutter capable of cutting to a depth of 1.8 m. The conveyor may be raised for unloading operations. The cut plant material is conveyed into central storage area in the craft with a capacity of 60 m^3. There is a second conveyor in the bottom of the storage area. The direction of movement of both conveyors is reversed for unloading.

(c) Aquamarine Corporation (Waukesha, Wisconsin, U.S.A.)

Sawfish. The craft has paddle wheels, side mounted at the rear. In the bows are one horizontal and two vertical sickle blades in a U-configuration. The unit cuts a swathe 2.4 m wide and down to a depth of 1.5 m. The craft (one operator) can work in water as shallow as 25 cm. A petrol engine powers three hydraulic motors on the cutting assembly and one motor for each of the paddle wheels. (See also Bryant, 1973, on p.53)

(d) G. Bouwmeester (Sappermeer, Netherlands)

Boat sweeper. The boat can be either 3.5 m or 4.0 m long. They each draw 25 cm and can operate in waterways approximately 1.4 m wide. They are fitted with special sweeping knives. Also a side cutter bar is available for longer craft. Power comes from a 10 h.p. diesel engine with reverse gear which drives an anti-fouling propellor. Sweeping can be done at 4-5 km/hr or slower when using side cutting. One-man operation. A trailer is also provided which is fitted with roller track winch and cable for retrieving, launching and transporting the boat.

(e) Hockney Company (Silver Lake, Wisconsin, U.S.A.)

HC10 underwater weed cutter. A metal pontoon, which can be plastic foam filled, is 3.7 m long, 1.2 m wide, 30 cm deep and draws 13 cm. An H7 version also offered is slightly narrower. The boat has a rear mounted paddle driven by a 4 h.p. engine. A 4 or 5 h.p. engine drives a horizontal sickle bar 3 m wide. There are two vertical cutter bars on each side. Cutting depth is from 13 cm to 1.5 m. A smaller version, HP 7, can be bought as a unit to fit to any suitable flat-bottomed boat.

(f) Krinke and Kruger GmbH (Hanover, Federal Republic of Germany)

A range of cutter bars of different sizes and power are offered which may be fitted to different sized boats. These are propelled by non-clogging Archimedean-type screws.

(g) John Wilder (Engineering Ltd.) (Wallingford, Berks, England)

Wilder water weed cutter. A double-skinned fibre glass hull, with flip-up ends, has side mounted, independently hydraulically-driven paddles. It is fitted with a U-shaped cutter with flexible, reciprocating, hydraulically-powered blades working against a fixed blade. Cutting can be made down to a depth of 1.7 m. Cutting width is 3.5 m. Cutting can be changed to work ahead of, or behind, the boat. Power is from a 15 h.p. diesel engine. The boat can turn easily in narrow waterways. A trailer is available to launch and load the cutter. A rake foreloader is available to deposit debris well back from the water's edge.

(h) AOA Research and Development (Orlando, Florida, U.S.A.)

Underwater weed cutter. This is a manually operated device which has two double-edged serrated blades, each 15 cm long and fitted to a handle, with handle extensions 1.5 m long.

Frye, O.E., 1972 Weed control as it relates to the aquatic environment. Hyacinth Control J., 10:12-3

This author contends that the one big advantage of mechanical harvesting is the removal of nutrients from the water. But unfortunately the relatively high expense has not permitted full exploitation of this advantage. It is therefore important to find a use for the end product so as to obtain a return to offset the cost. Possible uses suggested include paper-making, food supplements for livestock, mulch, and a source of protein. To date no commercial use (in the U.S.A.) has been found for either water hyacinth or submerged plants.

Golueke, C.G. and W.J. Oswald, 1965 Harvesting and processing sewage grown algae. J.Water Pollut.Control Fed., 37(4):471-98

The authors extensively studied methods of harvesting planktonic algae. There were three stages in the process:

(a) Initial concentration. This involved bringing the algal solids concentration from that in the pond to 1-2% of the wet weight of the slurry. Chemical precipitation or centrifugation were the best of many methods tried. Centrifugation required ranged from 3 300 to 6 200 kW of power per ton of dried algae when the pond concentration was 200 mg/litre with outputs of 100-300 g/min.

(b) Suitable flocculating agents included alum, lime and polyvalent cationic polymers. Figures are given for the amounts of chemicals needed to achieve different degrees of clarification of the water.

(c) The algal slurry was dehydrated as a thin film on a heated drum, a method which sterilizes the product and improves digestibility. Alternatively, the algae may be dewatered and air-dried in one operation on specially prepared sand beds. About 1 470 m^2/ha is required. The costs of these operations are discussed.

Grinwald, M.E., Harvesting aquatic vegetation. Hyacinth Control J., 7:31-2 1968

The author points out that nutrient removal from lakes is often necessary to maintain natural resources in the best possible condition. Mechanical weed removal is one way to accomplish this end both economically and effectively. It has the following advantages:

(a) it can provide immediate relief from local nuisance conditions;

(b) it probably does not tend to alter plant to animal life balances as drastically as may be the case with chemical treatments;

(c) it does not introduce foreign substances into the water;

(d) by removing nutrients it should tend to reduce the rate of lake filling by plant residues.

Cutting should be followed by extraction and disposal of the cut material. Otherwise it may block channels and cause a nuisance by decomposition.

A detailed description, with photograph, is given of the unit built by the Grinwald-Thomas Corporation in Wisconsin, U.S.A. The capacity of the equipment is 0.4 ha/hour in medium to average weed growth, and it can remove 6 t of weed per hour under average conditions.

Mechanical harvesting has proved effective against Myriophyllum spicatum which is difficult to control by chemicals.

A channel in Lake Pewaukee, Wisconsin, kept clear of heavy weed over a period of four years by mechanical harvesting, did not require harvesting during the fifth year. Weeds on either side of the channel were as dense as ever. At another site (Rib Lake, Wisconsin) after two years of harvesting practically none was required the third year. Water clarity and fishing conditions have been reported to have improved considerably.

Grinwald suggests that good records of harvesting work are needed together with studies of the consequences of harvesting on plant/animal relationships.

Hughes, H.R., Research into aquatic weeds in New Zealand waterways: a review. Inf.Ser. 1976 Dep.Sci.Ind.Res.N.Z., (116)

Reviewing work done in New Zealand the author refers to experiments on weed cutting and mechanical harvesting (which are unpublished).

The N.Z. Electricity Department devised a weed pulveriser, a machine capable of harvesting and discharging to shore wet pulverised weed. Netting booms, 3.7 m deep, were made to collect weed drifting into the penstocks of hydroelectric generators. The booms were fitted with alarm systems to give warning when critical masses had accumulated.

Koegel, R.G., et al., 1973 Increasing the efficiency of aquatic plant management through processing. Hyacinth Control J., 11:24-30

The authors have investigated the main problem which limits the rate of mechanical harvesting. That is the high water content of the plants. They give a diagram showing the total matter of the plants divided into: surface water, 44.5%; cellular water, 45.5%; solids, 10%. Thus for every 10 kg of aquatic plants collected, 9 kg of water have to be transported in order to harvest 1 kg of dry matter.

They therefore carried out a series of experiments to measure the amount of water that could be mechanically expelled from the plants by cutting and pressing without an unacceptable loss of useful nutrients in the expressed liquid. Treatment also included heating the material with a view to causing cell collapse and precipitation of protein to allow easier extraction of liquid and, at the same time, better retention of the protein. The plant used in the studies was Myriophyllum spicatum (Eurasian water milfoil). The following table summarizes their results after pressing for 1 hour at 7 kg/cm^2:

Treatment	Initial moisture content %	Final moisture content %	Dry matter in expressed liquid %
Control	93.5	88.9	0.39
2 min at 100°C	92.5	73.0	0.64
3 min at 100°C	93.6	71.4	0.92

Little, E.C.S., 1975 Harvesting aquatic weed - a neglected opportunity. N.Z.Farmer, 96(8): 46-8

This paper suggests that the problem of aquatic weeds in New Zealand lakes should be treated as an opportunity to carry out experiments on harvesting and utilization. From this work advice could be given to developing countries with similar problems. Thus if the costs were considered as a form of foreign aid the economics of the use of harvesting machinery would be subordinated to the research and development needed. The author states that harvesting has the supreme advantage that it is directly under control, whereas herbicide spraying can be affected by unpredictable gusts or updrafts of wind.

Harvesting from boats in calm waters enables man to take the weeds where and when he wants, and in the right amounts. The work can then be done with the minimum of disturbance to people using the amenities. No pollution is involved by this method, and the status of nutrients in the lakes, weed obstruction, algal blooms and general pollution are under control. If the weeds are put to use they can then help to pay for the costs involved.

Livermore, D.F., H.D. Bruhn and B.W. Pollock, 1971 Processing characteristics of subsurface macrophytes of Madison, Wisconsin, lakes in relation to mechanical harvesting systems. Hidrobiologia, Bucharest, 12:341-50

The authors have investigated various methods by which the large quantities of water typically present in aquatic weeds may be reduced in order to facilitate and cheapen disposal costs. The weeds in their trials were mainly Myriophyllum spp. and filamentous algae. Harvesting of such weeds involves transporting about 9 tons of water for every ton of dry matter.

(a) Fluidising. The process involved macerating the plants by hammer milling through fine screens, or by an agricultural field forage harvester equipped with a fine recutter screen. In some cases the fluidised material was pumpable through self-priming pumps without the addition of water. It was concluded that a substantial reduction in labour might be accomplished by transporting aquatic vegetation to disposal areas as liquid rather than a fibrous bulk material.

(b) Dewatering. Three methods were tested:

(i) Centrifuging of unprocessed plants successfully removed surface water, but within practical radial acceleration limits did not remove cell moisture.

(ii) Crushing between rollers resulted in moisture reduction from 87% (wet basis) to 78% on the third pass. By improving the removal of expressed moisture, reduction to 76% on the first pass was accomplished. By the addition of rubber matting to the roller surfaces, to increase the time of pressing at a given roll speed, the degree of dewatering can be further increased with additional passes. Reductions from 86 to 65% have been attained. Higher roll pressures result in an increasing degree of dewatering on each pass and also a higher percentage of the dry matter being discharged with the liquid fraction.

(iii) Screw pressing, using a conventional industrial processing machine, commonly used to separate liquid and fibrous fractions of various types of material. Such machines are expensive and have high power consumption because of internal friction on the material being dewatered. But the capacity and consolidation on the fibrous fraction makes them worth study.

Detailed results are given in the paper on the amount of liquid expressed at a range of pressures (from 1.4-5.2 kg/cm^2). This removed from 45-63% of the original weight. Two passes through the machine raised these figures to 70-78%. Losses of dry matter in the expressed liquid were measured. At 2.1 kg/cm^2 the content was 5% of the dry matter, of which less than 25% was protein. The power needed was measured. It was concluded that 2-4 horse-power hours per 450 kg of material processed at normal harvesting rates is about as much as can be employed economically.

(c) Combustion. Results showed that material dewatered to 65% wet basis should support combustion. But agitation of the material, during combustion, would be necessary. Using a fuel oil burner and retort, higher moisture material has been incinerated. It was pointed out that if the harvested material were reduced to ash then transportation and disposal would be reduced to a minimum. Also it was found that while some livestock would not eat the dewatered fibrous fraction they readily consumed the same material in a partially dehydrated and charred condition.

The conclusion of the studies was that harvesting and transporting of aquatic vegetation can be made 4-6 times more productive by providing processing equipment in the harvester barge. However, harvesting rates may be limited if discarding the expressed liquid from the harvester barge unduly upsets water conditions. Research is needed into this aspect.

Mara, M.J., 1976 Estimated values for selected water hyacinth by-products. Econ.Bot., 30(4): 383-7

Reviewing the possible uses of water hyacinth the author states that mechanical harvesting seems to be the best means of control for environmental reasons: it does not harm fish, it leaves no environmental residues and, since water hyacinths remove

nutrients from the water, mechanical harvesting improves water quality. Harvesting also makes water hyacinths available for various uses which, if a market for them can be developed, would help defray the cost of mechanical control.

Nichols, S. and G. Cottam, Harvesting as a control for aquatic plants. Water Resourc. 1972 Bull., 8(6):1205-10

This paper describes the effects of a series of harvests on the subsequent growth of Myriophyllum spicatum. The experiments were on a plot scale (30 m x 30 m) so harvesting was by hand as close to the bottom of the lake as possible. The objective was to determine the effectiveness of harvesting on the control of the weed rather than primarily for its utilization. The results showed that one harvest reduced growth by at least 50%; two harvests reduced it by 75%, and three virtually eliminated plant material for the year. Harvesting also reduced biomass the following year, especially in deep water. Three harvests had the greatest effect but two harvests were not far behind. The work thus showed that harvesting could have a carry-over effect into subsequent years. Moreover, if harvesting was done just before the two growth peaks of M. spicatum (in early June and early August, but progressively later at greater depth), the best effect would be achieved because this would remove the maximum biomass.

Thus by properly timing a harvest it may be possible preferentially to select against the weed and release more desirable species. Or a single release cutting could open up dense stands, making the areas available to fish and wildlife.

Robson, T.O., 6. Control of aquatic weeds. 6.1. Mechanical control. In Aquatic 1974 vegetation and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp.72-84

The author reviews water weed harvesting in regard to control of the weeds rather than particularly for utilization. He points out that the development of new machines and the modification and improvement of existing equipment depends on further investment of capital which will only be made if adequate returns can be expected. Much will depend on finding profitable uses for the harvested material and economic methods for handling and processing it. Impetus will also come from the need to avoid excessive eutrophication and pollution and, in some countries, the need for animal food.

The paper describes in detail, with illustrations, various types of mechanized weed cutting and harvesting machines, including weed cutting boats, reciprocating cutters, methods of propulsion of boats, and conveyors for collecting floating cut material.

The author also reviews papers on mechanical harvesting as developed in the U.S.A.

Robson, T.O. and L.F. Fillenham, Weed control in land drainage channels in Britain. 1976 Paper presented to the Sixth Session of the Working Party on Water Resources and Irrigation, Seville, Spain, 15 p.

In a paper devoted to water weed control the authors describe equipment which could be employed for weed harvesting. The equipment includes hand-operated power tools, tractor-based equipment, hydraulic and drag-line excavators, weed cutting attachments, and weed boats. A table shows the approximate stretch of machines working from one side of drainage channels. (From Weed Abstracts)

Steward, K.K., 1970 Nutrient removal potentials of various aquatic plants. Hyacinth Control J., 8(2):34-5

The author comments on the comparative ease of harvesting floating plants compared with the difficulties presented by the need to cut rooted and emergent types.

Sy, Se Hiong, 1974 Mechanical management of aquatic vegetation. Ph.D. Thesis, Wisconsin Univ., U.S.A., 254 p. (Cited in Weed Abstr., 25(10):3023 (1976))

A study was made of methods by which water could be extracted from water weeds in order to assist the harvesting of aquatic plants. When water was expressed under constant pressure it was shown that there was an "initial rate" of water released followed by a "falling rate" period characterized by a slow decay in the rate of moisture expression.

Thompson, T.W. and H. Hartwig, 1973 Control of watermilfoil in large Wisconsin lakes. Hyacinth Control J., 11:20-3

The authors point out that mechanical harvesting leaves root systems intact and so does not significantly increase water turbidity. Since vegetable matter is removed from the lake the problems of oxygen stress, phytoplankton blooms, and the accumulation of unsightly masses of decaying vegetation are avoided. Because no toxic materials are employed dangers of fish kills or damage to sport fishing are not present. Fishing may even be improved by opening channels through the weed beds.

An interesting additional point is that mechanical operations may promote good public relations by frequent demonstrations that positive action is being taken to improve the environment. To test public reaction a survey was taken of the attitude to mechanical harvesting of weed. Of 1 370 replies, 1 139 felt that the service should be extended, 179 suggested that the present levels of spending should be continued, and only 52 felt that the programme should be cut back.

The problem weeds in this instance were Myriophyllum spp. Analysis of the costs of mechanical harvesting showed a figure of U.S.$21.38/acre ($53.00/ha). This figure was less than anticipated and was attributed to the experience gained and the use of improved equipment. These units were a Grinwald-Thomas GT 501 harvester, a GT 471 Craneveyor, 2 transport barges, and a 1970 Aquamarine H 650 harvester with T 650 transporter.

The most serious problem is the transport of the heavy wet material to a disposal area. But after tests with chopped and dewatered Myriophyllum it has been found possible to sell the product as a soil conditioner and thus meet some of the transport costs.

The authors also point out the need for faster operating equipment (their rate was too slow at 1.6 km/hour). Cutter bars need to be made more able to withstand damage from underwater obstacles. It is also important for the cutters to be able to operate in all weathers, especially in strong winds.

U.S. National Academy of Sciences, National Research Council, Making aquatic weeds useful:
1976 some perspectives for developing countries. Washington, D.C., Agency for International Development, 175 p.

Mechanical harvesting methods are briefly reviewed. Illustrations are given of experimental and commercial harvesters. These include the large machines built by the U.S. Army Corps of Engineers, which used "clam shell" buckets to clear massive infestations of water hyacinth before the use of the herbicide 2,4-D provided a simpler and cheaper method of destroying the weed. Various sizes of weed cutters and collectors are shown mounted on large and small boats. Equipment has been made to enable floating weeds to be dragged on board with protection against damage to the gear from unseen underwater obstructions. Also shown are the "Hyballer" machine which picks up water hyacinth and flings it to shore, and flotation shoes which enable observers to walk over water and floating weeds.

Wunderlich, W.E., The use of machinery in the control of aquatic vegetation. Hyacinth
1967 Control J., 6:22-4

The author describes the design in 1937 by the U.S. Army Corps of Engineers of a diesel electric barge, "Kenny", needed for the removal of water hyacinth and alligator weed from extensive infestations in waterways.

The vegetation was lifted by a 5-m wide chain and slat conveyor at a maximum speed of 30 m/minute. The lower end could submerge to a depth of 1 m. Usually it was operated just below the surface because this gave clean and sharp action and prevented vegetation from piling up and then being picked up in large heaps. Speed could be controlled, or reversed, if logs or other debris too large to pass through the machine had to be rejected. Circular saws, 1 m in diameter, were fitted as outriggers to the conveyor. These cut the weed mat into a ribbon which facilitated pick-up by the conveyor. From the conveyor the vegetation passed into a hopper and thence between two corrugated rollers 30 in. (75 cm) in diameter and operating under 18 000 kg pressure. The crushed plants were rejected over the side by conveyor. The barge was propelled by two full-weedless propellors mounted in tunnels. All equipment was powered by electric motors supplied by two main generators giving 220 V DC.

The barge was capable of clearing 1 million m^2 of surface vegetation per month. It worked until 1951 when the use of herbicides replaced mechanical clearing.

For bankside clearance in shallow water, smaller units were constructed with 5-m side conveyors also fitted with saws which delivered the weed vegetation to 1-m wide side conveyors for depositing the cleared material onto the waterway banks. One unit had a high speed side conveyor to catapult the material ashore. To supplement the collectors small boats with rakes mounted over the bows were used to sweep weed toward the conveyors.

Another method of destroying the vegetation, rather than collecting it, was to use saw boats. These were fitted with banks of closely spaced circular saws revolving at 800-1 000 revs/min, and were satisfactory against both hyacinth and alligator weed. A modification, to combat water chestnut, had in addition a horizontal underwater cutter bar and a collecting trough.

Fish will leave the area when cutting is in progress but will return in large numbers when it is over. Fishermen have not made any objections to mechanical clearing since the operations do not appear to harm fish to any great extent.

Mechanical clearance tends to be more expensive than chemical because of the initially higher cost of the equipment. However, it can usefully complement chemical control methods.

Yount, J.L. and R.A. Crossman, Eutrophication control by plant harvesting. Part 2. 1970 J.Water Pollut.Control Fed., 42(5):R173-83

Experiments with water hyacinth showed that harvesting these plants from lakes reduced the productivity of the water. Therefore large-scale harvesting from such waters would reverse the trend towards hypertrophy, especially in polluted waters. The authors state that it is evident that the usual method of treating water hyacinth as a pest and destroying it with chemical sprayers returns nutrients contained in the plants to the water and thus exacerbates hypertrophy of the lakes.

Recognizing the difficulty of lifting and transporting masses of plant material containing up to 95% water, the suggestion is made that air-drying before transportation may be a solution. It is proposed that floating platforms be anchored in the lake on to which the freshly harvested weeds would be dumped. When dry to 20-30% of their wet weight the weeds could then be collected, say, for stock feed.

Anon., United Kingdom. Paddle boat mower for weedy waters. New Sci., 37(584):362 1968

A short note, with illustrations of a cutter mounted on a 5-m glass fibre boat and propelled by paddles. It has a draught of only 25 cm and can easily be transported by road. The cutting mechanism, suspended behind the boat, consists of a large U-shaped knife with a movable serrated blade moving over a fixed one. The bottom, horizontal part of the knife cuts at a standard maximum depth of 1.4 m., and the two arms of the blade are inclined outwards so that a wedge-shaped channel, 2.6 m wide at the bottom, is cut through the weeds. The position of the arms is controlled by hydraulic rams. (See Deutsch (g), p.57)

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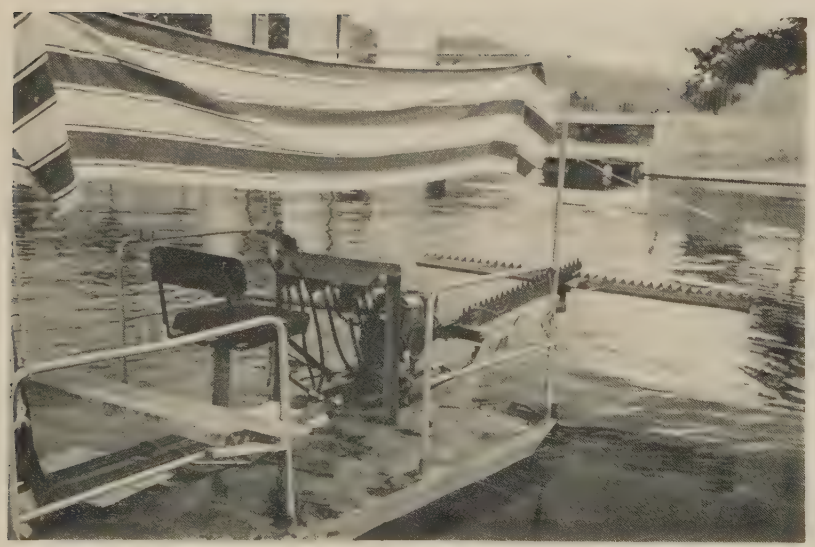

Dugong weed cutter on Kirkgözlü lake, Antalya, Turkey

V. PROTEIN EXTRACTION

The International Biological Programme (1964/74) included in its work investigations into "those unused, and little used, plant and animal products which might be converted into nutritionally exploitable materials by bio-engineering techniques." Three international meetings were held, all on the subject of novel protein resources. The last, held in India in 1970, was specifically on leaf protein. The proceedings were edited by N.W. Pirie and published in 1971 as IBP Handbook No. 20, "Leaf protein: its agronomy, preparation, quality and use". Pirie, who is well known for his extensive work on the subject, wrote two of the chapters, surveying in detail experiments and equipment on protein extraction which include data on water plants (see analyses cited in Chapter III) and 17 of his papers, up to 1970, are listed in the bibliography. A detailed review by C.E. Boyd in the same publication is mentioned in the references given below.

For protein analyses of many aquatic plants see Chapter III.

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Boyd, C.E., Fresh water plants: a potential source of protein. Econ.Bot., 22:359-68 1968

The author records the protein extractability data and the protein yield for a range of aquatic plants. He also mentions the ease of protein extraction. The summarized data is tabulated below:

Species	% Pulp N extracted as protein N	Comment[1]
Justicia americana	29.5 - 53.6	A
Sagittaria latifolia	25.2 - 27.4	A
Alternanthera philoxeroides	35.8 - 42.6	B
Nymphaea odorata	36.2 - 61.0	B
Orontium aquaticum	41.9 - 43.8	A
Jussiaea decurrens	34.2	C
J. peruviana	35.0	C
Brasenia schreberi	35.8	C
Elodea densa	33.6	A
Nuphar advena	21.8	C
Polygonum sp.	20.3	C
Nymphoides aquaticum	16.1	B
Nelumbo lutea	13.9	A
Hydrocotyle sp.	28.1	A
Ceratophyllum demersum	32.2	A
Myriophyllum braziliense	14.5	A
Najas guadalupensis	39.4	A
Hydrodictyon reticulatum	27.4	A
Spirogyra sp.	20.4	A
Pithophora sp.	15.2	A

1/ A. No difficulty in grinding or making extract.
B. No difficulty in grinding, contained slight mucilage but extracted well.
C. Contained excessive mucilage. Difficult to grind and extract.

Commenting on these results Boyd points out that they were ideal, laboratory, figures based on minimal losses during processing. In addition, slightly more protein was precipitated from the extract by trichloracetic acid than by heating to 80°C, which is the method of coagulation used in large-scale production. Laboratory efficiency is probably not possible with large-scale machinery, but the data are indicative of species which lend themselves to extraction.

Boyd, C.E., 1971 Leaf protein from aquatic plants. In IBP Handb., (20):44-9

The author points out that exploitation of aquatic plants for leaf protein will present unique problems in each locality, depending on species availability, harvest technique; environmental conditions and various other factors. Therefore development of this resource must be on a regional or local basis. In addition it may often be more practical to test various species by trial and error rather than follow an elaborate experimental approach. He suggests a programme which may be useful in utilizing aquatic plants as a crop for leaf protein extraction:

Development of a leaf protein resource from aquatic plants

(i) Small-scale screening of local species

(a) Extractability of protein
(b) Yield of protein per unit area
(c) Local abundance of promising species.

(ii) A. Large-scale extraction trials
B. Research on harvesting

(a) Harvesting equipment
(b) Timing of harvest for maximum protein yield
(c) Regrowth
(d) Propagation
(e) Ecological studies of promising species

(iii) Nutritive value and acceptance of protein

(iv) Cost analysis

(v) Bulk production

Boyd, C.E., 1974 7. Utilization of aquatic plants. In Aquatic vegetation and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp.107-14

After briefly reviewing work on protein extraction, the author records the amounts obtained from a few species suitable as raw material for protein. He found that the leaf protein from aquatic plants was similar in chemical composition to leaf protein from crop plants.

Species	Leaf protein yield kg/ha
Justicia americana	590
Alternanthera philoxeroides	478
Sagittaria latifolia	362
Nymphaea odorata	197
Polygonum sp.	180

He adds that research should be extended to other species.

Cifuentes, J. and L.O. Bagnall, Pressing characteristics of water hyacinth. J.Aquat. 1976 Plant Manage., 14:71-5

This paper is concerned primarily with the problem of pressing water out of the plant to facilitate harvesting (see Chapter IV). The authors found that juice loss during pressing increased as plant particle size decreased, as indicated below (Carver pressing cage at 1100 kPa):

Treatment	Fluid expressed (%)
Whole plants	17.5 ± 6.4
Chopped 25-mm pieces	23.8 ± 5.1
Minced	52.7 ± 3.1
Thoroughly blended	57.5 ± 15.6

Thus water hyacinth should be minced, or otherwise very finely divided, before or during pressing to maximize water removal. Such reduction destroys the fibrous structure of the plant allowing the pressure to be applied to the fluid, and damages cells, exposing the fluid for random drainage. Filtrate opacity increased as particle size decreased, indicating higher loss of solids. Juice expression increased rapidly with increasing pressure up to 600 kPa, but higher presure did not remove much more juice. Agitation of the residual cake between additional pressings increased juice expression by 10-20%. The protein content of the juice is shown in the following table:

Analyses at pressures ranging from 172-1380 kPa

Sample	Dry matter (% wet)	Crude protein (% dry wt.)
Liquid	1.05 ± 0.20	66.4 ± 12.8
Solid	9.57 ± 0.93	18.0 ± 0.9

Note: None of the analyses correlated significantly with pressure.

*Datta, R.K., et al., Leaf protein - preparation of protein concentrate from leaves of 1966 water hyacinth. Sci.Cult., 32(5):247-9

Of various methods of comminuting the leaves a blade-type hammer mill was found to crush satisfactorily both tender and fibrous leaves. Various extracting agents were used at the rate of about three times the weight of agent to the crushed mass. Stirring took place for 30 minutes. After filtering (by centrifuge) the protein was precipitated by bringing the pH of the filtrate to 4.0 with commercial hydrochloric acid, followed by heating to 80°C. The results are tabulated below.

Extracting solution	Extraction time (min.)	% Total protein extracted (N x 6.25)
Water	15	10
Water	30	11
Water	60	12
Ether-saturated water	30	7
Sodium chloride 2%	30	12
Sodium chloride 5%	30	15
Sodium carbonate 0.5%	30	63
Sodium carbonate 1%	15	57
Sodium carbonate 1%	30	64
Sodium carbonate 2%	15	60
Sodium carbonate 2%	30	77
Sodium carbonate 2%	60	80
Sodium carbonate 4%	60	69

As a result of the above tests a standard extraction was selected of 2% solution of aqueous sodium carbonate, for 30 minutes.

Tests were also made of the effect of pH on efficiency of protein precipitation.

Resultant pH of the extract	% of protein precipitated (N x 6.25)
7.0	65
6.0	72
5.0	80
4.5	87
4.0	92
3.8	96
3.5	96
3.6	90

Thus pH 3.8-3.5 was chosen as being the most effective range for maximum protein precipitation.

It was noted that heating to 100°C of the extract without acidification brought about coagulation of the protein to the extent of 70 to 80%. Prior acidification to pH 3.8 is not only helpful in affecting coagulation of most of the protein of the extract, but made the coagulum large enough to allow quick setting.

Centrifuging the slurry removed adhering hydrochloric acid, sodium chloride, and some disagreeable odour and taste. At this stage the product looked yellowish green.

When drying the protein in a tray, at 60°C, in a current of air, it was found that case hardening of the protein cake, which slowed the process, could be avoided if the moist material was washed with a little alcohol. When drying in the sun, or at a high temperature, the green-coloured protein changed to brown.

Koegel, R.G., et al., Increasing the efficiency of aquatic plant management through
1973 processing. Hyacinth Control J., 11:24-30

The authors describe mechanical methods of processing aquatic plants in order to reduce the quantity of water they contain for subsequent easier disposal. The plant they worked with was mainly Myriophyllum spicatum. They show that a well designed screw press may reduce the moisture of plant material by 60-65%, reducing the weight and volume of the fresh plant material to one third and one sixth of the original values. At the same time less than 20% of the nutrients in the plant material are lost in the expressed liquid.

They found that heat treatment facilitated mechanical dewatering and also caused protein denaturation or coagulation. The protein molecules then lost their water binding ability. This coupled with the inability of the cell wall to maintain osmotic pressure, or possibly even rupturing the cell walls, facilitates the passage of the liquid. Coagulation causes entrapment of the cellular matter and hence results in smaller amounts of this matter being lost with the liquid.

*Oyakawa, N., W. Orlandi and E.O.L. Valente, The use of Eichhornia crassipes in the
1965 production of yeast, feeds, and forages. Proc.Int.Grasslands Congr., 9(2): 1707-10

The authors state that water hyacinth has a promising food potential. But as it is relatively poor in protein content they studied how this deficiency could be overcome. They worked on a method of growing yeast on the macerated weed, as follows:

(a) wash the plant thoroughly, including the roots;
(b) total grinding in a liquifier or grinding mill;
(c) sterilization in an autoclave for one hour, at one atmosphere;
(d) juice extraction, while the material is still hot, through a press;
(e) centrifuge on press filter;
(f) add plain water in a quantity equivalent to the volume of the juice obtained (approximately 6 litres of water to 10 kg of fresh plant);
(g) mix both liquids to obtain a density of 1.009 at 20°C.

This is the culture medium for the multiplication of selected micro-organisms. It has a composition of:

reduced sugar and glucose	0.85%
total solids	3.8%
pH	5.5-6.0

A yeast found growing on the surface of decaying water hyacinth was chosen. It was Saccharomyces cervisiae var. ellipsoideus.

Growing method. Growing on a semi-industrial scale is done in a fermenting vessel with a capacity of over 20 litres equipped with an aerator, an agitator, temperature control, flow rate control of the broth and sample collector. The material of the vessel should permit sterilization and cleaning. At the beginning the vessel is filled to 25% of its volume with sterile broth of water hyacinth, the pH of which must be corrected to 4.4 by using H_2SO_4. Then the media is inoculated with 20% volume with a suspension which must contain at least 50 x 106 cells/ml of the yeast. At the same time, the broth is agitated and aerated with sterilized air at not less than 5 litres/minute for each 10 litres of liquid. This aeration is necessary to avoid an undesired production of alcohol which will reduce the yeast yield. The temperature is maintained at around 33°C. After five hours the vessel is filled to capacity with sterilized broth of water hyacinth. Agitation and aeration are still necessary.

Six hours after the vessel has been filled (i.e., after a total of 11 hours), the velocity of cell multiplication will reach a maximum of a growth logarithmic curve which corresponds to a population of two billion cells/ml., equivalent to the origin of one cell from another in two hours time. During this phase a constant quantity of yeast can be obtained simply by substituting every two hours about 25% of the juice already fermented by another amount of sterile broth. Obviously, all the conditions described before should be well maintained in relation to the aeration, pH, etc. The production may continue indefinitely since contamination by foreign micro-organisms is avoided, which may easily be maintained for the first 15 days. Every phase of growing should be followed by direct microscopic checks which will indicate multiplication, contamination, etc. The juice from the propagator contains in suspension the yeast cells which may be separated by filtering or preferably by centrifuging, from which the consistency obtained is creamy, with approximately 35% of total solids. This yeast cream has a very agreeable odour and flavour, and may even be used for human consumption. It may be dehydrated and ground, giving a powder of brownish colour with the same properties already described and of the following chemical composition:

	%		%
moisture	8	protein	52.7
lipides	4	glucides	27
mineral salts	7		

If concentrates for animal feeding are wanted, the dry and ground yeast is utilized only as a source of protein and vitamins, and the dehydrated water hyacinth bagasse is utilized, resulting from the broth fermentation, as a source of carbohydrates and mineral salts. The final product has a good appearance, with good volume and its odour is similar to that of the fish meal. It may also be used in concentrates.

The yield of yeast based on total sugars in the juice varies from 160-210% for the wet yeast with 35% of solids and 42-50% for the dried yeast with 8% of moisture. On an average, each kilogram of fresh plant yields 12 g of pure dried yeast with 52.7% of protein. The yield of the bagasse with 8% of moisture is about 3.5%. As an average, 1 kg of fresh water hyacinth may produce 42 g of a mixture of yeast and bagasse with a minimum of 28% of protein.

Considering that this plant contains an average of 96% water and that 1 kg of plant material may yield, in 11 or 12 hours, 12 g of yeast with 52.7% of protein, or 6.32 g of pure protein, we get a high rate of plant conversion into high quality protein, calculated as 6.5:1 per hour which never can be obtained by the digestion of any efficient herbivore. The protein obtained can be classified according to its analytical values as between that of egg protein (100%) and leguminous protein (50%) with an average of 87%.

Taylor, K.G., R.P. Bates and R.C. Robbins, 1971 Extraction of protein from water hyacinth. Hyacinth Control J., 9(1):20-2

The authors decided it was not practicable to extract protein only from the leaves under the harvesting system used to remove the weed from the waterways, so they worked with the whole plant using two different methods.

(a) A Hiller harvesting machine chopped up the plants into coarse particles which were then passed through a screw press. The juice obtained was clarified in a centrifuge, then acidified with concentrated hydrochloric acid to pH 3.8, and heated to 80°C. It was refrigerated for 36 hours at 1°C after which the precipitate was filtered off.

(b) Small samples of whole hyacinth plants (1 kg) were chopped and then comminuted in a 4-litre capacity blender with 3 kg of 0.05 N sodium hydroxide (NaOH) at low, medium and high speeds for 20 seconds each. The slurry was passed through a screw press with a 0.02-inch (0.05 cm) screen. The juice was then clarified, acidified to pH 3.7 and heated to 80°C; it was refrigerated overnight at 1°C and the precipitate was filtered off.

The results were: Process (a). The press juice was dark green and appeared unacceptable for human consumption without excessive clean up. Also it was too low in protein (0.15%) for the clean up to be economically feasible. The low recovery of protein may be due to lack of sufficient crushing to release the protoplasm from a high proportion of cells. Also the pH of 6.6 did not appear to be conducive to maximum yield.

Process (b). Comminution, as opposed to chopping, improved the quantity of protein extracted from 23% to 37%. Two or three minutes' comminution were no more effective than one minute. The pH (9-12) of the extraction fluids was much higher than from chopped material.

Further work with hyacinth, containing 5.4% dry matter and 0.43% (fresh weight) crude protein, showed that a 1:3 ratio by weight of hyacinth to 0.05 N NaOH gave the best results. A yield of 49.4% of the crude protein of the whole plant was obtained.

Another test with water hyacinth having 5% dry matter and 0.235% (fresh weight) crude protein yielded 33.6% of the crude protein on extraction.

The authors comment that the yield of protein from the whole hyacinth plant is low compared with the extractions from legumes, reported by other workers, of 50-80%. It is possible that a greater proportion of the protein of the whole hyacinth plant is associated with fibrous structural material, rather than with chloroplasts as in leaves.

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Giant water hyacinth from Guaiba river,
Porto Alegre, Brazil

Water hyacinth
on island beach,
Rangoon, Burma

VI. AQUATIC PLANTS FOR HUMAN FOOD

Some aquatic plants have a long tradition as human food. Boyd (1974, p. 107) writes: "Rice, Oryza sativa is an emergent aquatic plant and the only vascular hydrophyte which is a major agronomic species. It is one of the world's main crops and forms the staple diet of over half the world's population. A small but important number of other aquatic crops exist, such as water chestnut (Trapa spp), lotus (Nelumbo nucifera) and watercress (Nasturtium officinale). Ipomoea aquatica is one of the few aquatics grown as a green vegetable." (See also Edie and Ho, 1969, below)

What is needed is knowledge as to how many other aquatic plants, especially those which grow in profusion and thus are described as weeds, may be usefully converted to human food, because this is obviously more efficient and rewarding than having first to feed the plant material to an animal for conversion into edible products.

One of the pioneers of the concept of protein extraction from aquatic plants for human food is N.W. Pirie (see Chapter V).

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*Alford, L.W., Alligator weed - a good cattle food. Chemurg.Dig., 2(9):10-2 1952

Alligator weed (Alternanthera philoxeroides) has so much mineral content that it should be introduced for human food, as salad or garnish. Eaten in small quantities it has produced no ill effects. It tastes better than some of the common salad greens and is much improved with salt and salad dressing.

Bates, R.P. and J.F. Hentges, Aquatic weeds - eradicate or cultivate? Econ.Bot., 1976 30(1):39-50

In their review of the possible uses for aquatic plants (referred to in Chapter II), the authors include a section on "Human food potential".

Boyd, C.E., Fresh water plants: a potential source of protein. Econ.Bot., 22:359-68 1968

Discussing the amino acid content of some aquatic plants (see Chapter III), Boyd points out that the samples were somewhat low in lysine and methionine when compared to meat proteins. Phenylalanine was present in very small quantities in Alternanthera philoxeroides and Sagittaria latifolia. Otherwise amino acid levels were similar to those for meat proteins and crop plant leaf protein isolates; so leaf protein from aquatic plants was of sufficiently high amino acid quality to be useful as a dietary supplement.

Boyd says that for natural vegetation to be useful as food, large stands containing sufficient quantities to justify harvest must be present. Stands should also be monospecific so that the quality of the product is somewhat predictable. Many aquatic weeds fulfil these conditions. "Utilization of water weeds as food could probably alleviate protein shortages in local populaces of many developing nations, but it is doubtful that these plants could contribute greatly to the total food supply of any nation... Exploratory research to assess the food value of the native aquatic flora should be initiated in nations that presently have severe protein shortages."

Boyd, C.E., 1968a Evaluation of some common aquatic weeds as possible feedstuffs. Hyacinth Control J., 7:26-7

Discussing the nutritive value of aquatic plants (see Chapter III) which often contain "as much or more crude protein, crude fat, and mineral matter, than many conventional forage crops", the author states that people in tropical countries "located near weed infested waters could benefit greatly if the plants were used as food. Aquatic plants could temporarily help alleviate food shortages until lasting agricultural and social solutions are found."

Edie, H.H. and B.W.C. Ho, 1969 Ipomoea aquatica as a vegetable crop in Hong Kong. Econ. Bot., 23:32-6

Ipomoea aquatica, water spinach, is related to the sweet potato. It has a long history of use as a vegetable in China where it is known as "Ong Tsoi". It is widely distributed around the world. The paper describes both dry-land and wet-land cultivation of two local varieties of this plant in Hong Kong.

I. aquatica grows satisfactorily only when the mean temperature is above aboug 25°C and is therefore available in Hong Kong only during the summer months. The young stems, complete with leaves and petioles, are picked and used as a green vegetable, usually cooked by frying in oil, the final product being tender and crisp but without any very pronounced flavour.

Annual production of water spinach in Hong Kong varies between 3 and 5 million kg, and during the peak months it supplies almost 15% of local vegetable output, not counting the considerable quantities used as pig food.

Dry-land cultivation. Of the two local varieties of I. aquatica 'Ching Quat' (green stem) is more resistant to cold and is grown during spring and early summer from March to May. The system of cultivation is very similar to that used for other leaf vegetables such as cabbage, where the crop is grown on raised beds separated by irrigation ditches. Seed is either sown directly onto these beds or seedlings from a nursery are transplanted. The plants are finally spaced at approximately 12-cm intervals by the time they are 15 cm tall. Heavy applications of fertilizer are given. A typical crop might receive the equivalent of 3 100 kg/ha of night soil every two to three days once the plants are past the seedling stage. Irrigation is an important factor. If there is sufficient water available to flood the irrigation channels between the raised beds, water is splashed over the plants. This must be done three to four times daily when the plants are young, reducing to twice daily once the crop is established. Hand weeding is required frequently, especially when the plants are young. Water spinach grown in this way is ready to harvest 50 to 60 days after sowing and the entire plant is pulled up, washed and packed in baskets for transport to market. A small amount of the other local variety 'Pak Quat' (white stem) is also grown by the dry-land method during the summer. This variety gives a much larger plant of better quality, having fleshier, more succulent stems and petioles. Usually several harvests are taken from a single crop by cutting the shoots above ground level and encouraging lateral growth.

Wet-land cultivation. This is the much more common and important method of water spinach cultivation and provides most of the summer main-crop produce. Variety 'Pak Quat' is almost always used. Fields for wet-land cultivation are flat and surrounded by raised banks. It is common to find watercress (Nasturtium officinale) grown in the same fields during the cooler winter months. As germination and initial growth of I. aquatica is poor under water, seedlings are normally raised on a dry portion of a field. Some six weeks after sowing, cuttings are taken from the

nursery plants for transplanting. Each cutting is a portion of stem about 30 cm long with seven or eight nodes and is planted out in the field at 40 cm spacing. Before transplanting, the field is prepared by flooding to a depth of 3-5 cm and tramping the soil into a liquid mud in which the cuttings root quickly without further treatment. Water is allowed to flow gently through the field and as the crop becomes established the depth is increased to some 15-20 cm. Fertilizer application is similar to that used on dry-land water spinach, continuing as long as the crop is in the field. It is common to stop the flow of water through the field for 12 hours after each application. Overhead irrigation is not necessary, and weeds are no problem except in the nursery beds.

Growth of the crop is rapid, and 30 days after transplanting the first harvest is taken. The upper portion of the main shoot is removed at about water level, stimulating lateral growth of the plants which produce the typical horizontal shoots carrying vertical branches. In subsequent harvests, which are taken every seven to ten days throughout the summer, it is the vertical branches which are picked and marketed. Ten or more such harvests can be taken and the total yield averages 90 000 kg/ha. During September the plants begin to flower and harvesting stops. The fields are drained to encourage the reproductive stage and eventually the ripe fruit are harvested, dried in the sun, then trodden gently to release the seeds which are stored in air-tight containers for use the following season.

*India, Council of Scientific and Industrial Research, The wealth of India. Vol. 3.
1952 Raw materials. New Delhi, CSIR, pp.130-4

Water hyacinth is reported to be used as a table vegetable in Formosa.

Koegel, R.G., et al., Increasing the efficiency of aquatic plant management through
1973 processing. Hyacinth Control J., 11:24-30

Referring to their work on processing of aquatic plants for protein extraction (see Chapter V) the authors comment: "The protein concentrates may have a use for human nutrition as well as for animal nutrition."

*Malik, H.C., It pays to grow Singhara and Bhen. Indian Farming, 11(8):23-4
1961

The author advocates the use of pools and low-lying areas on farms to cultivate water chestnut (Trapa natans (known locally as 'singhara') and lotus species (known as 'bhen'). The culture of these plants and their uses are described.

Singhara bears fruit in summer. It is common in almost all states of Northern India but is extensively grown in Uttar Pradesh, Madhya Pradesh, Bihar and Orissa where the high rainfall results in the collection of water in ponds and other low-lying areas. The root, flowering stems, young fruits and seeds of bhen are also used as food in different ways in different parts of India. The flowers and seeds of bhen are also used as medicine. Both these crops grow luxuriantly in standing water and mud in ponds, and are highly paying in the hands of people who have acquired the skill and technique to grow them.

Singharas are used both fresh and in the dry state; the nut is ground into flour which is used for highly nutritious and edible preparations. The fruit is rich in starch and manganese and contains more calcium, phosphorous and iron than rice. There are three varieties of singharas, green with spine, red with spine and green

spineless. The red one is the sweetest. The yield of singharas varies considerably; it may be 14 000 kg/ha if the crop is good, but much less if the crop has been attacked by beetle and has not been saved in time. In 1962 it was possible to obtain a return of 1.7:1 on costs.

Bhen is a nutritious and palatable vegetable, alone or in combination with other vegetables. There are two varieties of bhen, red and white; both are equally delicious and palatable. The crop on an average yields from 3 700–4 700 kg of roots per hectare. In 1962 the author calculated that income from the lotus crop would be greater than the cost of growing it in the ratio of about 4:1. This included selling the vegetative parts, seeds and flowers, as well as the roots.

*Oyakawa, N., W. Orlandi and E.O.L. Valente, The use of Eichhornia crassipes in the 1965 production of yeast, feeds, and forages. Proc.Int.Grasslands Congr., 9(2): 1707–10

The authors describe a method for growing yeast on water hyacinth as a substrate (see Chapter V). They say: "This yeast cream has a very agreeable odour and flavour and may even be used for human consumption."

*Pirie, N.W., Water hyacinth: a curse or a crop? Nature, Lond., 185(4706):116–7 1960

This frequently cited paper briefly introduces the idea that water hyacinth, and especially the protein extracted from it, could be used as fodder for animals or even for human food. Referring to the basic principles of protein extraction, the author points out that the process is very simple. "The fresh leaf is pulped and the juice, neutralised if necessary, is separated. It carries with it much or most of the protein and this is coagulated and filtered off as a dark green cake which generally has little flavour after washing with water. It can be used as it stands in various dishes that are reasonably palatable, or a stable protein can be made by extracting the chlorophyll and lipids with a solvent."

This paper has contriubted as much as any towards orienting the minds of many people towards the possibilities of utilization of vigorous weeds such as water hyacinth and thus considering them as potential crops.

Pirie, N.W., Leaf protein as human food. Science, Wash., 152(3730):1701–5 1966

The author reviews the history of extraction of leaf protein for human food and includes the water hyacinth among a range of plants which, either as whole plants or with leaves as by-products (e.g., sugar cane, jute and the sweet potato), have been neglected as a source of human food especially in developing countries. He points out that "leaf protein judged by its amino acid content appears to be nutritionally better than the seed proteins and as good as animal proteins other than the exceptional proteins of egg and milk... However the dark green colour and faint spinach or tea-like flavour gives leaf protein little immediate appeal to many people. It is easier to get immediate acceptance if the material is decolourized by solvent extraction, but experience shows that most people accept the novel appearance in a few weeks; the extra process of decolourization seems therefore to be both unnecessary and wasteful. Furthermore dark coloured and sometimes greenish foods are already part of the normal cuisine in many countries."

Quimby, P.C. and E.L. Robinson, Calcium oxalate in alligator weed and silverhead.
1975 Proc.Annu.Meet.South.Weed Sci.Soc., 28:264-5 (Abstr.)

The authors found that the calcium oxalate content of Alternanthera philoxeroides (alligator weed) was a maximum of 4.4% of the dry weight of nitrogen-fertilized terrestrial shoots. They state that: "This is well below the amount of soluble oxalate (about 20%) found in poisonous plants such as Halogeton. Nevertheless the level is high enough to be of interest to nutritionists and medical personnel in those countries, e.g. Burma, where alligator weed is being used for human food. About 4 g of oxalic acid is the minimum fatal dose for an average sized man. Thus 100 g of fertilized terrestrial alligator weed (on a dry weight basis) could potentially provide a fatal dose if the toxic principle were not solubilized and removed by boiling before eating. Diets with high oxalate-containing vegetables and low calcium have sometimes been implicated in the incidence of kidney stones."

Sculthorpe, C.D., The biology of aquatic vascular plants. London, Edward Arnold, 610 p.
1967

This book has a section entitled "Hydrophytes as sources of food" (pp.514-7). The author begins by citing historical references to the use of the dried and ground seeds of water lilies Nymphaea caerulea and N. lotus in ancient Egypt for bread; the Egyptians also ate "the sweet, quince-like rhizomes of N. lotus which when cooked resembled egg-yolks". The culms of Cyperus papyrus were also chewed raw, boiled or roasted. He says that in the Orient Nelumbo nucifera has been widely cultivated and its fruit and rhizomes used in a variety of cooked and fresh dishes for many centuries, as also have the rhizomes of Sagittaria trifolia, the floury seeds of the lily Euryale ferox, and the starch- and fat-laden horned fruits of Trapa spp. The fruits of T. bicornis, T. natans and T. incisa form a staple food in continental Asia, Malaysia and India.

Cultivated rice, Oryza sativa, is an aquatic food crop throughout the world. Its wild relative O. perennis is a grain food in parts of Africa. Canadian wild rice, Zizania aquatica, has been eaten by North American Indians for over 300 years and is now grown commercially in the U.S.A.

Still eaten in various tropical countries, when food is scarce, are the seeds, rhizomes, petioles and peduncles of Nymphaea caerulea, N. capensis, N. lotus and other lilies; the seeds of Enhalus acoroides, Victoria amazonica and V. cruziana; the swollen tubers of Aponogeton species and Cyperus esculentus, and the rhizomes of Typha latifolia and T. angustifolia. The rhizomes of several species of Sagittaria, and the rhizomes and seeds of Nelumbo lutea and Orontium aquaticum have been an important carbohydrate source for the North American Indians. The dried and powdered rhizomes of Butomus umbellatus, Calla palustris and Menyanthes trifoliata have been extensively used to make bread by the Eskimoes and other people of northern Eurasia.

In India young leaves, stems and roots of Ipomoea aquatica are eaten, and both there and in Malaysia the foliage of Ottelia alismoides, and all the plant (except roots) of Monocharia hastata and M. vaginalis are eaten. In Java juvenile plants of Limnocharis flava are a common vegetable. Several species of Ceratopteris are cultivated as a green salad crop in parts of Africa and tropical Asia. In temperate regions watercress, Rorippa spp., is cultivated.

Sculthorpe points out the dangers of bacterial and other diseases from eating inadequately washed vegetation from stagnant or slow-flowing waters, especially in the tropics.

Steenberg, B., 1968 Papyrus: problems in its utilization for pulp and paper making. In Pulp and paper development in Africa and the Near East. Rome, FAO, vol. 2: 865-76. FAO Accession No. 03952-68-MR

In this paper on Cyperus papyrus the author briefly refers to the use of the young roots as human food.

Taylor, K.G. and R.C. Robbins, 1968 The amino acid composition of water hyacinth (Eichhornia crassipes) and its value as a protein supplement. Hyacinth Control J., 7:24-5

Analyses of water hyacinth have been summarized in Chapter III. The paper discusses whether the amino acids of water hyacinth could serve as a supplemental source to improve the nutritional quality of grain proteins. "Lysine and tryptophan are the first two limiting amino acids in grains, therefore interest centers on the concentration of these two amino acids in water hyacinth. Since any tryptophan present would be destroyed by the acid hydrolysis, only lysine can be considered at present."

The authors tabulate data, collected from the literature, of amino acid content of cow's milk, corn grits, leaf protein concentrate and water hyacinth compared to the FAO reference pattern:

Amino Acid Content (%)

Amino acid	Water hyacinth	FAO ref. pattern	Cow's milk	Corn grits	Leaf protein conc.
Methionine	0.7	2.2	2.4	2.5	2.1
Cystine	11.6	1.9	-	1.1	0.7
Phenylanaline	4.7	2.8	4.9	6.4	6.0
Tyrosine	3.0	2.8	5.1	6.7	4.2
Threonine	4.3	2.8	4.6	4.1	5.2
Lysine	5.3	4.2	7.8	0.8	6.3
Isoleucine	4.3	4.2	6.4	6.4	5.3
Valine	0.3	4.2	6.9	5.3	6.3
Leucine	7.2	4.8	9.9	15.0	9.8

They comment that water hyacinth protein shows deficient levels in only two of the essential amino acids, valine and methionine, as compared to the FAO reference pattern. A diet containing an adequate protein level will be balanced in lysine if it contains 4.2% of that amino acid in its protein content. Corn is deficient in lysine, containing only 0.8%. However water hyacinth contains 5.3% lysine, while milk contains 7.8%. It is evident that water hyacinth could serve to improve the lysine content of a corn diet. Leaf protein which contains 6.3% lysine has been reported to be an effective supplement for barley in pig rations. Then present evidence indicates that water hyacinth could be used to improve the lysine content of grains.

"If subsequent work on tryptophan content of water hyacinth reveals that this amino acid occurs in substantial amounts, the protein of hyacinth may be developed into useful dietary supplements for grain diets, especially in the underdeveloped countries. If a number of uses are found for the other constituents of water hyacinth so as to make processing economically feasible, the protein could be extracted. Such a protein concentrate could be used as an effective supplement to grains for animal or human consumption."

U.S. National Academy of Sciences, National Research Council, Making aquatic weeds
1976 useful: some perspectives for developing countries. Washington, D.C., Agency for International Development, 175 p.

This book has a valuable chapter of 20 pages, including 17 illustrations (Chapter 14) devoted mainly to the use of aquatic plants as human food. The authors state that in most parts of the world there are swamp lands and shallow ponds totally unsuited to fish culture or agriculture. The present policy for such areas is to drain and "develop" them for uses not in accord with their nature. There is a need to find techniques that will allow us to use wetlands as wetlands. Cultivating aquatic plants is one possible way. The chapter highlights a few species that, with research, could become important aquacultural crop plants. Some of these plants are pernicious weeds. They should never be introduced to new locations or encouraged to spread in old ones. They are included for the benefit of those areas that already have them and would like to see them used productively.

The plant descriptions, distribution and uses which are briefly given include: water spinach (Ipomoea aquatica), watercress (Nasturtium officinale), Neptunia oleracea, Limnocharis flava, Ceratopteris thalictroides (a fern), Ottelia alismoides, floating rice (Oryza sativa), wild rice (Zizania aquatica), lotus (Nelumbo nucifera), Chinese water chestnut (Eleocharis dulcis), taro (Colocasia esculenta), swamp taro (Cyrtosperma chamissonis), arrowhead (Sagittaria trifolia), and spirulina (Spirulina platensis), an alga. Literature references to all these plants are also included.

*Villadolid, D.V. and D.M. Bunag, New uses for water hyacinths. Philipp.Fish.Yearb.,
1953 1953:80-1, 241-2

Water hyacinths have been used as human food in the Philippines in war time. The soft white bud of the plant was eaten either raw, or as a salad, or as an ingredient in vegetable dishes. It was called 'repollo' (cauliflower). Under conditions of relative food abundance it is considered unlikely that it would still be used as food.

Zafar, A.R., Economic significance of certain species of Scirpus sp. In Aquatic weeds
1976 in South East Asia, edited by C.K. Varshney and J. Rzeska. Proceedings of a Regional seminar on noxious aquatic vegetation in tropics and sub-tropics, New Delhi, 12-17 December, 1973. The Hague, Dr. W. Junk, B.V., pp.387-91

Discussing various uses of species of the sedge Scirpus, the author states that "the fibrous roots of S. maritimus are said to bear high food value, while the culm can be used as fodder."

VII. AQUATIC PLANTS FOR LIVESTOCK FOOD

The primary value of livestock in agriculture is to convert plant material which is unsuitable for human food into meat, hides, wool, dairy and other products. The dung and urine from the animals and the waste products from their carcases can be used as fertilizer for crops and forage. Because the majority of aquatic plants have little, if any, value as human food, a practical form of utilization of this resource is as fodder for livestock. If aquatic plants are considered in this way then it is appropriate to treat them as a forage crop and consider whether they can best be used fresh, dried as hay, or preserved as silage, and also for which kinds of livestock they may be the most appropriate and profitable to use.

A disadvantage of an aquatic crop as fodder for livestock is that it can rarely be fed *in situ* because of the depth of the water, hazards from mud and pathogenic organisms, or the contamination of the water by the animals. Thus, although the crop takes up no useful land and costs nothing to grow, the expense of harvesting (as discussed in Chapter IV) has to be met. Fish or aquatic animals can be used to graze the crop without harvesting, and are dealt with in Chapter VIII).

There is an extensive literature on the use of aquatic plants as fodder. The subject has been reviewed by the Indian Council for Scientific and Industrial Research (1952) and Boyd (1974). Boyd, by his extensive work on the analysis of aquatic plants (see Chapter III), has contributed significantly to information on the potential uses of aquatic plants for animal nutrition. Villadolid and Bunag (1953) have given a short but useful review of the uses of water hyacinth for animal, fish and human food. Sharma (1971) has also discussed the uses of water hyacinth for livestock food.

Gaevskaya (1966, in Russian) gives a general review of the utilization of aquatic plants by animals. This book has been reviewed by Davis (1970) who writes: "The author has done a great service by reviewing the world's literature. She finds that the higher plants are consumed by a wide variety of animals including insects, birds and mammals. Plants considered, in addition to all those truly aquatic, are various sedges and other plants growing in and near to water. There is a total of 550 references of which 200 are from non-Soviet journals."

The National Academy of Sciences, National Research Council, U.S.A. (1976) has a chapter (No. 5) on ducks, geese and swans in its book "Making aquatic weeds useful". The advantages and disadvantages of farming these birds to help control aquatic vegetation in Central Europe, Greece, Hawaii, New Guinea and South Africa are discussed. Chapter 6 deals with the potential for farming water buffalo, pigs and the domesticated rodents capybara and nutria. The dangers of introducing these rodents to new areas are emphasized. Reference is made to the harvesting of water hyacinth in Bangladesh, India, Indonesia and the Sudan to feed livestock.

The National Council for Research, Sudan, and National Academy of Sciences, U.S.A. (1975) have included in their book a chapter (No. 5) on feeding animals with aquatic plants which grow in the Sudan. The literature on this subject is reviewed (13 references). The advantages and limitations are discussed. The authors conclude that during the dry season water hyacinth could usefully be fed to cattle, buffalo, sheep, goats and poultry. Other forage such as *Typha* spp. shoots exist in abundance along the banks of the White Nile and could be fed to ruminants, and also *Lemna* spp. which could be fed to poultry. A call is made for more and detailed research into all aspects of livestock utilization of aquatic plants.

The University of Florida, Gainesville, U.S.A., has carried out a great deal of work on the utilization of aquatic weeds for stock foods. Papers from various authors involved are referred to in the following pages.

In a review specifically about Azolla spp. Moore (1969) notes that in Indochina Azolla (with or without other aquatic plants, e.g. Lemna, Eichhornia, Pistia, Salvinia, etc.) is collected from ponds and ditches and fed to pigs and ducks. It is claimed that Azolla developed the body fat of these animals. In Vietnam it is reported as food for cattle, poultry and fish. In Singapore Azolla is common in tanks used by Chinese to grow Pistia for pig food. In Formosa its use for pigs is normal. The author comments that, judged by its analysis (see Chapter III), Azolla should provide good quality forage.

For convenience, this chapter has been divided into uses of aquatic plants as food for cattle and sheep (1), pigs (2) and poultry (3), and as preparation for silage (4).

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1. Cattle and Sheep

*Alford, L.W., Alligator weed - a good cattle food. Chemurg.Dig., 2(9):10-2 1952

The author discusses the spread of alligator weed (Alternanthera philoxeroides) in South Carolina, U.S.A. He describes how in the 1890s the plant occupied areas formerly cultivated with rice. By 1925 the plant was being widely used for all-round cattle feed, but mainly in the winter. In 1941 systematic farming of areas of South Carolina infested with alligator weed was carried out. (For analyses see Chapter III.) The land was periodically flooded, as for rice cultivation, as a means of promoting the weed growth. The resultant feed was adequate for a stocking rate of 7.5 cows/ha for about 300 days in the year. Under flooded conditions the plant is protected under water against frosts and provides good winter feed. It grows to 30-45 cm above the water and sometimes roots into the soil, but much of it floats with stems 120-440 cm long intertwined in a dense mass about 45 cm below the surface.

The cattle wade, sometimes almost swimming, into the fields to graze. They readily eat the dead part on top, then pull the green stems from below the surface.

The weed can also be harvested for stall fodder. The author reports on the success of farmers planting alligator weed on new land by scattering chopped up portions of the stems onto muddy soil. He says that alligator weed seems to make its best growth in the fresh-water areas of the tidelands where the streams run both ways. If the stream is shallow, it will root into the soil but it does equally as well or better where it floats on the surface. When floating, the underwater stems are four to ten times the length of the top portion. There are just a few short, fine roots at each joint. These float back and forth with the current and are constantly bathed in the dark water laden with plant food and minerals. Further up stream where the current is constant in its direction, the plant thrives in shallow water where it can root into the soil and not be washed away. The growth is very poor in still water, but it may respond to fertilizer.

Bagnall, L.O., Processed aquatic plants for animal nutrition. Annu.Res.Rep.Inst.Food
1971 Agric.Sci.Univ.Fla., 1971:49 (Abstr.)

Progress in cattle and pig feeding trials with water hyacinth and Hydrilla is reported. The rates of drying and pressing were measured at different temperatures and pressures, and also the tension, compression and shear strength of hyacinth. Dry matter is lost in the fluid expressed from the plants. Some can be recovered by filtration or centrifuging. The need for additives to the water plant fodder was also explored.

Bates, R.P. and J.F. Hentges, Aquatic weeds - eradicate or cultivate? Econ.Bot., 30(1):
1976 39-50

In this review of the utilization of aquatic plants the authors state that diets for cattle containing aquatic plants are accepted and consumed like diets containing land forages with no signs of toxicity. The seasonal variations in nutritive value of aquatic plants must be considered in preparing such forages. Care must be taken to exclude herbicide or pesticide residues, environmentally produced plant toxins or pathogenic organisms.

In general Hydrilla spp. appear to be as well tolerated by cattle and sheep as water hyacinth but neither is adequate as the sole component of the ration, being most effective at less than 33% of the organic matter in pelleted diets. Ensilage tests show that water hyacinth wet-press residue makes excellent silage when combined with additives which provide fermentable carbohydrates and absorb moisture, thereby preventing run-off of nutrients. The more nutritious press juice and its components have not yet been studied in livestock metabolism trials.

Boyd, C.E., Evaluation of some common aquatic weeds as possible feedstuffs. Hyacinth
1968a Control J., 7:26-7

In a review of the analyses of many aquatic plants (see Chapter III) the author states that on a dry weight basis many aquatic plants contain as much or more crude protein, crude fat and mineral matter as many conventional forage crops. Fibre values were usually lower than for forages. High quantities of tannin may decrease the digestibility of protein. Using aquatic plants as fodder would help to pay for harvesting, which is the best way to remove nutrients from lakes suffering from artificial enrichment. This is the only practical method. Harvesting should be done when protein content of the plants is highest for their maximum usefulness as feedstuffs.

Chalmers, M.I., Report to World Food Programme on a visit to Sudan. In Animal
1968 production WFP. Mission report on animal nutrition in Sudan. Study on the use of water hyacinths in ruminant animal feeding and also as a means of weed control. Rome, FAO, Acc. No. 02787-68-WS

Reporting on the potential of water hyacinth as a feed for ruminants the author states that because the protein and fibre are mainly in the lamina, and the carbohydrate mainly in the petiole (see Chapter III), the best results from ruminant feeding could be expected from feeding them together. Animals eating fresh water hyacinth as sole ingredient of the diet could not ingest sufficient dry matter, quite apart from the imbalance of the nutrients. On a dry matter basis water hyacinth is better than straw but a little low in protein to compare with hay. The

physical structure of the plant is not suitable for hay or silage making and the product would not have much nutritional value. It could be considered as roughage feed if processed to remove the moisture and compacted for easy transport. The nutritional value could be increased by mixing with molasses, at present a waste product in Sudan. If the molassed water hyacinth feed proved acceptable to livestock it could be introduced as the roughage component of feed used regularly to feed and finish animals held in quarantine for export, vaccination,or any large congregation of stock in and around Khartoum. It could also be used in a ration balanced with dura and oil seed cakes and could make a valuable contribution to beef fattening units. The hyacinth is rich in minerals, but it would be simple to incorporate any necessary food additives in the processing.

*Chatterjee, I. and M.A. Hye, Can water hyacinth be used as a cattle feed? Agric.Live-
1938 stock India, 8:547-53

The authors refer to the common habit of cattle and buffaloes browsing on water hyacinth in shallow water (which is still being done), a habit encouraged by the annual flooding of large areas of the country. It is also common for villagers to collect water hyacinth and sell it as cattle fodder in Bengal. In order to measure the feeding value of hyacinth the authors carried out long-term (up to one year) feeding trials in which hyacinth was fed as a mixture with rice straw, with and without the addition of linseed cake (0.45 kg/day). As the trial animals were not accustomed to water hyacinth the authors describe the methods adopted to introduce them to the plant. Straw was given at one feeding in restricted amounts. Then at the second feeding of the day hyacinth only was offered. When no added linseed cake was offered the animals took to the hyacinth more quickly, but there were considerable variations between animals in their acceptance of the hyacinth. There was also variation in preference between the leaves and stems of the plants. The results of the trial showed that animals fed on hyacinth and straw only lost weight, but with the addition of the cake they were able to maintain weight or achieve a slight gain. The authors conclude that the results might have been better if the test animals had been chosen from cattle known to be adapted to water hyacinth browsing. They add:

"It will be noted that the digestible nutrients in hyacinth compare quite favourably with green fodders like Guinea grass or Napier grass and show an apparent superiority over rice straw (Aus or Aman). This superiority would have been real if the palatability of hyacinth had not come in the way. It is just possible that this lack of palatability is associated with a heavy percentage of potash and chlorine. The presence of such a heavy quantity of potash probably reacts on the general mineral metabolism also. The tests on the mineral side were limited but the few done show that the feeding involved an ingestion per 500 lbs of about 96-106 g of K_2O, 18-20 g of chlorine, 48-65 g of CaO. The potash and chlorine balances were clearly negative and though lime ingestion was high, the balance figures were 50% negative.

"It will thus be seen that hyacinth can hardly occupy a high place as a fodder. If its value had been high, popular usages would have already forestalled it on an established footing. But here we are faced with its existence more as a necessary evil; and the problem is not so much as to establish it as a fodder but to explore the avenues of its possible utilization. The experiment shows that under the singular circumstances in which the country is placed, the moderate use of hyacinth as a fodder can be permissible, but in order that full benefit is derived from it, it should always be fed in combination with cake or concentrate and still better in a combination of a number of feeds."

Combs, G.E., J.F. Hentges and R.L. Shirley, Processed aquatic plants for animal
1973 nutrition. Annu.Res.Rep.Inst.Food Agric.Sci.Univ.Fla., 1973:81 (Abstr.)

Voluntary intake of water hyacinth by sheep and cattle was highest with treatments containing 4 kg dried citrus pulp and 1 kg sugar cane molasses per 100 kg of hyacinth press residue.

*Davies, H.R.J., Effects of the water hyacinth (Eichhornia crassipes) in the Nile Valley.
1959 Nature, Lond., 184(4692):1085-6

The following is an extract from the paper:

"In most areas the effect on animal dry-season grazing appears negligible. In some areas where this grazing, exposed by the falling rivers, usually called 'toich' in the Nilotic regions of the Sudan, is limited it is possible that the powerful Eichhornia may restrict the growth of other more valuable forage grasses, whilst also it makes it more difficult for cattle to drink in safety from crocodile-infested rivers. An interesting situation is to be found in the lower Sobat. Here the river is incised, with the result that the grazing exposed by the falling river is of very narrow extent. The cattle grazed near the river bank during the rainy season are taken towards better pastures along the White Nile during the dry season after that river has begun to fall. The most difficult time for animals along the lower Sobat is during the early dry season after the grass brought by the rains has dried up and before the Nile pastures are ready. At this period of the year Eichhornia, in spite of its low grazing value, provides a welcome source of green matter for the cattle."

*Dirven, J.G.P., The protein content of Surinam roughages. Qual.Plant.Mater.Veg.,
1965 12:172-84

Cattle feed on water hyacinth only in the dry season. It only has a low protein content, but that of Ipomoea reptans is more favourable.

Easley, J.F. and R.L. Shirley, Nutrient elements for livestock in aquatic plants.
1974 Hyacinth Control J., 12:82-5

The authors point out that public concern in the U.S.A. that aquatic plants should be removed mechanically from water rather than killed by herbicides may cause them to be available in quantity as livestock feeds. The study described in this paper was made to determine the range of concentrations of nutrient minerals in six aquatic plants throughout one year of monthly or bimonthly sampling. The plants were: Hydrilla verticillata, Eichhornia crassipes (water hyacinth), Ceratophyllum demersum (hornwort), Potamogeton pectinatus (pondweed), Vallisneria americana (eel-grass), and Najas guadalupensis (naiad). Tables are given of the maximum, minimum and average mineral concentrations found in these plants. Also shown are the daily requirements of a 300-kg steer in respect of these elements. The conclusions from these data are given in terms of the percentage of the animal's daily requirements present in 1 kg of dry matter of each plant. The figures are tabulated below:

Nutrient Elements

% concentration of animal requirements in 1 kg dry weight

Plant	Ca	P	K	Mg	Na	Fe	Cu	Zn	Mn
H. verticillata	300-600	10-26	50	100-160	100-200	70-140	63	33	100-200
E. crassipes	85	10-26	82	100-160	100-200	70-140	5-21	33	100-200
C. demersum	300-600	10-26	50	100-160	100-200	70-140	5-21	9-18	600
P. pectinatus	300-600	10-26	25	50-80	100-200	68	5-21	9-18	100-200
V. americana	300-600	10-26	50	50-80	100-200	70-140	5-21	9-18	100-200
N. guadalupensis	300-600	10-26	50	50-80	100-200	70-140	5-21	9-18	100-200

*Fish, G.R. and G.M. Will, Fluctuations in the chemical composition of two lakeweeds from
1966 New Zealand. Weed Res., 6(4):346-9

Describing lake weeds growing in the North Island of New Zealand, the authors state that in the summer cattle grazing on paddocks adjoining shallow weedy shores of Lake Rotorua will wade into the water and graze on Lagarosiphon in preference to the grassland pastures. "The dry-weight composition of these lake weeds is comparable with the normal dry-weight composition of leaves of rye grass (Lolium perenne). But although the lake weeds may provide a fodder that is both palatable and of good quality, their high water content (92% compared with 82% for Lolium perenne) diminishes their value as food for stock."

Gangstad, E.O., D.E. Seaman and M.L. Nelson, Potential growth of aquatic plants of the
1972 Lower Mekong River Basin, Laos-Thailand. Hyacinth Control J., 10:4-9

The paper discusses uses for aquatic weeds in Thailand. Because it is usually at hand, water hyacinth is used to feed water buffalo, cattle and pigs, and these uses have been mentioned as a means of control. But the plant has a limited food value (protein content 8-12% of dry weight). Its water content is too high for direct consumption and the cost of drying and transporting to dryers or feed-lots precludes its use for animal feed in quantities sufficient to control its growth and spread. The same would be true of the other noxious aquatic plants such as water lettuce and water fern.

Gortner, R.A., Lake vegetation as a possible source of forage. Science Wash., 80:531-3
1934

The author comments on the analyses of a variety of lake weeds (given in Chapter III). He states that the literature on the feeding value of aquatic plants (in 1934) was meagre. However there were European reports that Elodea canadensis was an excellent food for cattle and pigs. He added that there was no obvious reason why many types of lake vegetation should not be suitable feeding stuffs. The analyses indicate that they may be superior to much of the forage which is used on farms in the Great Plains area of the U.S.A. He adds that the uniformly high crude protein content of lake vegetation suggests the possibility of growing suitable non-leguminous plants in shallow lakes, and preparing from them concentrates for animal feeding. He predicts that a high protein, high lime, low fibre meal may be of commercial value. He observes that in thickly populated areas of Asia " a hectare of water may produce more than a hectare of land". Thus aquaculture, in suitable areas, may become part of changing agriculture.

Hentges, J.F., R.L. Shirley and G.E. Combs, Processed plants for animal nutrition. 1971 Annu.Res.Rep.Inst.Food Agric.Sci.Univ.Fla., 1971:67 (Abstr.)

Intake and digestion trials with steers were carried out comparing pelleted cattle diets made up with 33% of water hyacinth, or Hydrilla, or the grass Cynodon dactylon. On all diets the animals remained healthy and in positive nitrogen balance. Intake of the grass and the hyacinth mixtures was about equal, and each was higher than for Hydrilla mixture. The following table summarizes results:

Plant	Digestion coefficients %			Estimated digestible energy in diets	
	OM	CP	Cellulose	Mcal/kg DM	Mcal/kg OM
C. dactylon	72.4	65.2	37.3	3.3	3.4
Hydrilla sp.	70.5	47.9	54.1	2.7	3.2
E. crassipes (hyacinth)	66.0	51.7	31.3	2.8	3.0

The authors comment that in the aquatic plants nutritive value exists in the energy-yielding components but apparently not in the nitrogenous components, as processed for these studies.

Hentges, J.F., R.L. Shirley and J.F. Easley, Toxic substances and chemical composition 1973 of hyacinths and other water plants. Annu.Res.Rep.Inst.Food Agric.Sci.Univ. Fla., 1973:79 (Abstr.)

Hydrilla verticillata, Eichhornia crassipes, Ceratophyllum demersum, Potamogeton pectinatus, Vallisneria americana and Najas guadalupensis were analysed. Their mineral content was found to be within the range of land forages in the U.S.A. Sodium was 10–100 times higher and iron exceeded the range by 4–19 times. Phosphorus concentration was generally lower and calcium higher, except for E. crassipes which had about 2% Ca, the Ca/P ratio being suitable for cattle. H. verticillata in a lake contained 14 mg As/kg dry matter compared with 1 mg/kg in the river. E. crassipes from a lake contained 9 mg As/kg. (From Weed Abstracts)

*Hossain, W., Investigation of water hyacinth as fodder. Agric.Pak., 10(4):513–8 1959

The following is the author's summary of a feeding trial carried out:

"To study how far water hyacinth could be fed to animals a feeding trial was conducted over a prolonged period of more than two years. The investigation was conducted under different dietetic conditions:

(a) To start with the animals were given 10 lbs of fresh water hyacinth, 8 lbs of paddy straw, 2 lbs of gram and 1 lb of mustard cake. The animals were found to relish water hyacinth.

(b) Water hyacinth portion of the ration was increased gradually after reducing the other items.

(c) The animals were fed exclusively on water hyacinth for some time.

(d) Water hyacinth after being partially dried in the sun for about seven hours was fed, with 3 lbs of paddy straw and 1½ lbs of mustard cake.

Maximum consumption of fresh water hyacinth was 33 lbs together with 3½ lbs of paddy straw and 1½ lbs of mustard cake. This showed that water hyacinth was palatable if properly supplemented and when animals were accustomed to such feed. Previous workers postulated that lack of palatability of water hyacinth was probably associated with the presence of high percentage of potash and chlorine in water hyacinth. But in this experiment no such evidence could be noticed. Water hyacinth when fed as sole feed caused diarrhoea and this might be due to the presence of high percentage of alkali. It might be recommended that besides supplementing water hyacinth with mustard cake for protein and phosphorus it is also expedient to have 50 percent of the dry matter requirement from straw or hay to prevent undesirable laxity of bowels. Intake of water hyacinth fell during dry season and increased during monsoon when water hyacinth grew luxuriantly.

Consumption of water hyacinth did not improve when fed in partially dried condition, but the animals gained considerably in their live weights when water hyacinth, as one of the ingredients of the ration, was fed in partially dried condition. This might be the result of better assimilation of nutrients from the ration when water hyacinth was given in partially dried condition. From the general trend of the experiment and from the considerable gain in live weights in particular, it might be inferred that a ration composed of 40 lbs of fresh water hyacinth dried in sun to 23 lbs together with 3½ lbs of paddy straw and 1½ lbs of mustard cake might be allowed to animals weighing on an average 400 lbs for moderate production."

Ingvason, P.A., The golden sedges of Iceland. World Crops, 21(3):218-20
1969

Carex lyngbei, 'gulstör' or golden sedge, has been cultivated for hundreds of years for forage by seasonal inundations in a way similar to rice culture. It is also found in coastal Labrador and in the littorals of the eastern Pacific end of Siberia, where it is found in abundance and has a high rating as forage. In Iceland it has been shown that well cured hay made from gülstor is equal to upland meadow hay (Tada sp.) for feeding cattle and sheep. It keeps the animals healthy and vigorous.

The forage makes good silage without the addition of molasses or chemical preservatives. An average yield of silage per hectare is 8-12 tons. Records from one meadow in the western littoral show a yield of hay as high as 5 t/ha. In this case the soil was limy and manure may have been applied. In curing sedge hay it is best to let the stacks heat up a little and settle down well. This makes the hay palatable to the animals. C. lyngbei has been collected as seed from Iceland for sowing around lakes in Finland.

C. rostrata, blue sedge, is a large aquatic species forming fringe growth around lakes and ponds. It is excellent forage for cattle, which will wade deep into the water to reach it. It is widespread in Siberia and rated highly as a forage.

Knipling, E.B., S.H. West and W.T. Haller, Growth characteristics, yield potential and
1971 nutritive content of water hyacinths. Proc.Soil Crop Sci.Soc.Fla., 30:51-63

Citing the analysis of water hyacinth (given in Chapter III) the authors state that this favours the use of the plant as livestock food supplement.

Koegel, R.G., et al., Utilization of Eurasian water milfoil. Abstr.Meet.Weed Sci.Soc. Am., 1973
1973a

The relative abundance of Myriophyllum spicatum (Eurasian water milfoil) and the reports of its relatively high protein and xanthophyll content have led to interest in its utilization. The problem of high water content can be overcome by mechanical dewatering with minimal nutrient losses. In utilizing the weed its high mineral content and low fibre content relative to terrestrial forage plants is of importance. Blending of milfoil with conventional forage plants may be desirable to increase its acceptance as a livestock feed. Partial incineration also tends to increase its acceptance. (From Weed Abstracts)

Lancaster, R.J., M.R. Coup and J.W. Hughes, Toxicity of arsenic present in lakeweed. N.Z.Vet.J., 19(7):141-5
1971

Lagarosiphon major is a lake weed of importance in the North Island of New Zealand. It was investigated for usefulness as animal fodder using sheep as test animals. A difficulty is the high arsenic content of the weed (288 ppm), so the experiments measured the effect of this mineral on the animals and the amount of uptake. A lamb was force-fed with sufficient L. major to contain a toxic dose of arsenic. On slaughter the lamb was found to be healthy and unaffected by arsenic.

L. major and other important weeds, Elodea and Ceratophyllum, when fed to sheep were found to be unpalatable but were accepted when mixed with pasture (1:5 dry matter basis). The following is the authors' summary of the results:

'Four samples of lake weed were found to contain large amounts of fibre but small amounts of soluble carbohydrate. Levels of minerals and nitrogen were similar to those in high quality pasture herbage, but some high levels of arsenic were also demonstrated. To assess the toxicity of lake weed a ration of grass and 200 g of dried lake weed containing approximately 300 ppm of arsenic was fed daily to sheep for 21 days to give a mean daily uptake of 1.4 mg As/kg of body weight. All animals in the test remained healthy and examination of organs and tissues removed from the animals slaughtered at weekly intervals did not reveal any gross lesions or macroscopic changes. Small amounts of arsenic were retained in organs (maximum 3.8 ppm in kidney) but this had virtually disappeared four weeks after the cessation of lakeweed feeding (maximum 0.3 ppm in kidney)."

Little, E.C.S., From water weeds to milk. (Letter) PANS, 16(1):198-9
1970

The author describes an emergent weed problem on a farmer's lake in Kenya which was solved by cutting the weeds by hand and, after chopping them, stall feeding them to dairy cows as a supplement to their ration. The plant was Cyperus digitatus, a sedge about 2 m high. It took the cows a few days to become accustomed to this new fodder. When they did it was possible to increase the proportion of the sedge in the ration to 60% without any diminution in normal milk production. Thus the weed became a useful supplemental source of fodder when grass was not available in the dry season.

Mara, M.J., Estimated values for selected water hyacinth by-products. Econ.Bot., 30(4):
1976 383-7

The author has made a detailed economic assessment of the use of water hyacinth as livestock food. He considers the least cost diets for feeding cows and calves and steers (based on 1973/74 prices for feed). He calculates that if all the cattle in Florida (estimated at 2½ million in 1974) were fed at the rate of about 164 kg/year then about 450 000 t/year of hyacinth would be needed. This could be provided from

only about 1 000 ha of water surface assuming about 450 kg/ha of water hyacinth. This area is estimated to be only about 2.25% of the total area estimated to be infested. Thus livestock feeding is not a significant way of disposing of the amount of hyacinth available. In these calculations it was assumed that hyacinths were to be used at the point of harvest. If processing and transport costs were to be added for places distant from the hyacinth source then not even the low fraction of the ration mentioned could be considered. If feed costs rise then the use of hyacinth could become correspondingly more economically attractive.

Mishin, G.M. and I.F. Gribovskaya, (Ecology of Elodea canadensis in the reservoirs of central Urals). Biol.Nauki, 11(8):72-8 (in Russian) 1969

The biological characteristics, distribution and yields of Elodea canadensis are considered from the viewpoint of using the weed as a potential supply of food for livestock. (From Weed Abstracts)

Mrsic, V., Lake vegetation as a possible source of forage. Science, Wash., 83(2156): 391-2 1936

Commenting on the paper by Gortner (1934) the author states that in Yugoslavia it is a general custom for the peasants to use water plants as forage in districts subject to drought in summer and where there is abundant vegetation on the waters. Such vegetation commonly includes Myriophyllum, Potamogeton, Ranunculus and Callitriche. Nasturtium grows near springs and Sphagnum in lakes. The peasants cut these plants with scythes or pull them out with rakes, and feed them to cattle fresh. The cattle like the fodder and digest it easily. Vegetation growing in marshes, or in ponds used for carp breeding, or at margins of ponds, is not so palatable and is less productive of milk.

Nelson, W.J. and L.S. Palmer, Nutritive value and chemical composition of certain freshwater plants of Minnesota. Tech.Bull.Min.Agric.Exp.Stn., (136):1-34 1938

Working with Elodea, Myriophyllum and Vallisneria, which they analysed in detail (see Chapter III), the authors comment: "Of interest from the viewpoint of using these aquatic plants as a forage crop is the fact that they appear to contain all the vitamins in at least as high an amount as alfalfa. Of more interest is the fact that the biological value of the protein in Elodea is about 70% that of alfalfa and the digestibility is apparently better. Cystine seems to be the limiting amino acid in Elodea as well as in alfalfa. The low biological value and digestibility of the proteins in Myriophyllum and Vallisneria practically eliminates them as animal food. This might be one explanation for their unpalatability because if the right supplements of protein, fat and vitamins are made these plants seem to be eaten readily and give good gains. Under such conditions there is no evidence of any toxicity. This suggests the possibility that other plants might be found suitable for aquaculture. Elodea from lakes might be as satisfactory as from streams."

"All the plants were sufficiently rich in minerals so that at a 20% level in rations (dry basis) they would furnish all the materials needed in nutrition with the possible exceptions of P, Na and Cl."

Osman, H.E., G.A. El Hag, and M.M. Osman, The nutritive value of water hyacinth. In
1975 Aquatic weeds in the Sudan, edited by M. Obeid, Khartoum, Sudan, National Council for Research, pp.104-27

Detailed results are given of studies to determine the nutritive value of water hyacinth and its possibilities for use alone or with other foods in feeding ruminants during the dry season. It was evident that hyacinth alone or mixed with local grasses was poor quality roughage and would be unsuitable unless supplemented with high protein concentrates. Alternatively, palatability could be increased by adding molasses. (From Weed Abstracts)

*Oyakawa, N., W. Orlandi and E.O.L. Valente, The use of Eichhornia crassipes in the
1965 production of yeast, feeds, and forages. Proc.Int.Grasslands Congr., 9(2): 1707-10

The authors describe a method of growing yeast on water hyacinth as a substrate in Brazil and suggest that it may be used as a source of protein for animal feed (for details see Chapter V).

Pirie, N.W., Weeds are not all bad. (Water hyacinths and other pests can also be good
1970 animal fodder). Ceres, 3(4):31-4

The author states: "In principle ruminants are better adapted than single-stomached animals for eating water weeds. Buffaloes and cattle will eat hyacinth voluntarily. It is claimed that cattle do not like hyacinth because the crystals in it prick their tongue, and eat it only when there is no other fodder. I doubt this having seen animals eating hyacinth although there was grass on the edges of the pool. However if most buffaloes and cows do not in fact like hyacinth the dislike may be overcome by ensiling, wilting, crushing or some other form of pre-treatment.

"To establish the value of water weeds to ruminants we should experiment with the performance of a group of animals given diets in which the proportion of hyacinth is gradually increased compared with the performance of others on a conventional diet. It is important that the change should be gradual, that is, it should be 5% of the diet at first and be raised to 10% after two weeks, to 15% two weeks later and so on to give time for the rumen flora to adapt to the change in diet."

Pirie points out that Pistia floats and has potential as fodder. Salvinia he says is less useful because many forms are poisonous. He considers Justicia americana as promising and points out that Alternanthera philoxeroides is eaten by stock. Both these plants need testing critically.

*Ramarokoto, M.R., Water hyacinth in Madagascar. Working paper presented to the FAO
1965 Conference on Quelea and water hyacinth control. Douala, Africa. Rome, FAO, Working Pap.(WH/4)

"Water hyacinth has one advantage and one only. During the austral winter when all other grasses have dried out and have sometimes disappeared completely, the water hyacinth provides a considerable amount of feed which is relished by cattle. Sometimes it is sold commercially in the high plateau areas."

Shirley, R.L., J.F. Easley and J.F. Hentges, Toxic substances and chemical composition 1971 of hyacinths and other water plants. Annu.Res.Rep.Inst.Food Agric.Sci.Univ. Fla., 1971:65 (Abstr.)

Water hyacinth and Hydrilla verticillata were compared with Bermuda grass, Cynodon dactylon, as 33% components of pelleted diets for steers. Measurements were made of uptake of a range of minerals, oxalates, tannins and nitrates.

Analyses were made of Hydrilla, Ceratophyllum, Potamogeton, Chara and Vallisneria taken from lakes, rivers and ditches. From these data the authors concluded "that these aquatic plants were all liberally supplied with many nutrients required by livestock. It is apparent that the time of year and water from which the plants are obtained are factors affecting variation in composition."

Wolverton, B.C. and R.C. McDonald, Don't waste waterweeds. New Sci., 71(1013):318-20 1976

The authors state that the National Space Technology Laboratories (U.S.A.) have made a water hyacinth meal by drying whole green plants to moisture contents of less than 15%. This can provide a 10-20% supplement to the diet of beef cattle. Beyond this amount animals can suffer from a mineral imbalance due to the high levels of K, Fe and Mg normally found in water hyacinth. Other aspects of this work (reported in U.S. National Aeronautics and Space Administration, 1976) is the harvesting of water hyacinth from sewage ponds and drying and grinding this into a meal rich in minerals and proteins. This was fed to beef cattle mixed with corn silage. At the end of four months the weight gains were satisfactory, being comparable to a diet of cotton seed and soya bean meal. As the cost of fuel for drying the hyacinth meal is an impediment to its use, a prototype solar drier has been made. With this it is expected that 18 tons of wet material can be dried every 36 hours.

*Anon., Water hyacinth - a new use. Madras Agric.J., 38(1):27-8 1951

"Water hyacinth is an aquatic plant which has been looked upon as an unwanted and obnoxious material condemned as much by agriculturists as by irrigation authorities. Its prolific growth and spreading habit makes it all the more unpopular, for in watercourses it obstructs the flow of water and blocks the sluices thus impairing the efficiency of irrigation. Recently however, a new use has been found for this plant. Head loads of the plant weighing 50 lb are taken out daily for feeding buffaloes in the neighbouring area. It has been found that feeding the buffaloes with 15 lb of water hyacinth per day increases their milk by 10-15%, but the milk is rather watery and the butter extracted does not possess the proper consistency and flavour. Possibly a suitable combination of this feed with concentrates to be worked out by feeding trials might remove this defect. The nutritive value of the material is higher than that in grass. It is phosphoric acid alone that needs to be supplemented. The average yield per acre of water surface has been estimated at 60 tons per annum. Since the removal of this plant will be a great boon to the authorities, cuttings can be taken free of charge, and hence the buffalo feed is within the reach of every buffalo owner."

2. Pigs

*Hora, S.L., 1951 The water hyacinth problem and pig farming. Sci.Cult., 17(6):231-2

The author briefly reviews uses for water hyacinth, in particular as fodder for pigs. He cites reports that in China the plant presents no serious problem because it is kept in check by feeding to pigs. He also refers to the pig-fish-water hyacinth culture in Malaya (see Chapter VIII). He comments: "This Chinese economy of food production impressed us very much because the possibility of adopting similar practices seemed to be very great in India. It was learned that it was a very lucrative business. Though there is demand for pig flesh in all big cities, little attention seems to have been paid to pig farming in this country. Perhaps when we seriously take up piggery as an item on the "Grow More Food" programme, instead of eradication of water hyacinth we may begin to cultivate this weed as fodder for pigs."

*Le Mare, D.W., 1952 Pig rearing, fish farming and vegetable growing. Malay.Agric.J., 35(3): 156-66

The paper describes the use of Ipomoea reptans ('kangkong') as a means of extracting nutrients from fish ponds fed with effluent from pigsties. The plant was then returned to the pigs as fodder. From eight ponds, 1 m deep, with a total area of just over 1 ha, a harvest of about 112 kg/ha of kangkong was obtained, which rose to about 450 kg/day. (Details of the fish used in this system are given in Chapter VIII.)

*Ling, S.W., 1960 Control of aquatic vegetation. In Lectures presented at the Third International Inland Fisheries Training Centre, Bogor, Indonesia, 31 October - 10 December 1955, conducted by the Government of Indonesia and FAO with the cooperation of IPFC. Vol.1. Rome, FAO, (3•23):12 p.

The tender parts of water hyacinth are suitable as fodder for pigs.

*Little, E.C.S. (Ed.). 1968 Handbook of utilization of aquatic plants. Rome, FAO, Plant Production and Protection Division, PL:CP/20:123 p.

In an article, "Lake weed could make a useful crop" (reprinted in the first edition of the Handbook on p. 117), the author discusses the possibilities of utilizing lake weeds as feed for livestock. He suggests that pigs are obvious candidates because they are omnivorous, can deal with watery food, can tolerate crowded conditions under close control, and produce a diversity of meat which is all of high value and in constant demand. The turnover of pigs is rapid so that their population could readily be adapted to the amount of weed available.

Mahendranathan, T., 1971 Water hyacinth has value as pig feed. Pig Farmer, Malaysia (January issue):599-607

The author describes the system of pig farming using water hyacinth grown in ponds fertilized with human and animal waste. Pig feeding with hyacinth is well established in Malaysia. The hyacinth can be fed fresh after removal of the roots. Some people boil the plant. Pigs readily eat the hyacinth and thrive on it. Some

farmers have machines for slicing the plants into small pieces. The high vitamin content (A, B and C) and easy availability of the plant are important advantages. But the high moisture content and the possibility of the material being contaminated with pathogens seem to deter the extensive practice of fresh plant feeding.

Consequently most farmers (70–80%) prefer to cook the sliced hyacinth with other feed ingredients for 5 to 6 hours and feed the boiled material as a slop. It is usually boiled with tapioca chips, ground maize, rice bran, wheat bran, sago, groundnut cake and fish waste. Of the mixture the hyacinth forms 60–65% of the bulk. The boiling is believed to increase the digestibility of the fibre content of the hyacinth. It is also believed that the hyacinth acts as a laxative and is especially beneficial to pregnant sows and any animals that are off feed.

Silage is also fed to the pigs. It is made by chopping the hyacinth and wilting it in the sun for 2 to 3 days; it is then mixed with ground maize and molasses and stored for 1½ to 2 months in pits about 1 m wide and 2 m deep. The silage is used as 15–25% of the total feed. Farmers believe that pigs fed on this silage sleep longer, eat more, and show greater increase in weight. The author cites Choy and Deveraj (1958) who conducted a feed trial with pigs using rations containing water hyacinth. Each pig received daily a slop containing 1.54 kg of boiled water hyacinth and 2.4 kg of concentrate. The controls received dry mash ad lib. The pigs on hyacinth gained 1.54 kg/week while those on the mash gained 2 kg/week. Also cited are Fischer and Devendra (1963) who found that crossbred pigs fed on a slop feed containing water hyacinth showed a live weight gain of 0.48 kg/day at a feed conversion ratio of 3.38.

*Mahmud, E.A.B., The use of water hyacinth in animal feeding (pigs). A review – 1967. 1968 In Handbook of utilization of aquatic plants, edited by E.C.S. Little. Rome, FAO, Plant Production and Protection Division, PL:CP/20:49

The author reviews various results of using water hyacinth for pig farming in Malaysia. He says that "water hyacinth found mainly in ponds and slow-flowing streams of the rural areas of this country is used by Chinese pig rearers in feeding pigs. The weed is chopped into reasonably small pieces and together with other vegetable tops, like banana stalks, is then boiled. To this fluid is added rice bran, copra cake, groundnut cake, sometimes maize and salt. The proportions of water hyacinth in the mixture varies from farm to farm and, according to information gathered from the farmers themselves, it constitutes about 5–10% of the total ingredients."

Pigs from approximately 25 lb live weight are given this liquid feed. Pigs normally take longer to reach market weight of 133 lb on such feed than those fed with dry mashes. The causes of the delay could be due to the margin of nutrients above maintenance requirements being insufficient, and foods of high fibre content are indigestible for young pigs. In most cases pigs take about 7 to 10 months to reach the slaughter weight. Of course, this is not altogether a disadvantage because the manure is available to the farmer for his vegetables. In a trial with rations containing water hyacinth each pig received a slop consisting of 3.5 lb of boiled water hyacinth and 5.3 lb of concentrate given three times daily. Another group of pigs was fed with dry mash ad lib., and the weekly weight gains were compared. Pigs fed with wet mash containing water hyacinth gained from 2.5 to 4.6 lb per week, while those on dry mash gained from 2.6 to 6.5 lb per week.

Pirie, N.W., 1970 Weeds are not all bad. (Water hyacinths and other pests can also be good animal fodder). Ceres, 3(4):31-4

In this paper the author gives figures (cited in Chapter III) for the high N content of aquatic weeds which at certain stages of growth makes them equivalent to the best forage plants. These aquatic weeds are used as fodder in many parts of the world. In regard to fodder for pigs he states: "In Singapore water hyacinth is not a weed but a crop deliberately cultivated in well fertilized fish ponds for use as pig food. In the Philippines it is boiled and given to pigs... In India also it is collected for pigs and I have seen pigs eat it there of their own accord when they have access to the edge of a tank. In Canton, Pistia and other important weeds play an important part in pig feeding. It is unlikely that weeds would continue to be used so extensively if they were of no value as pig food. Nevertheless there is a point that should be properly established; it cannot be assumed that traditional techniques are invariably sound. If it could be established that a weed such as hyacinth, at a certain stage of growth, and pretreated in a specified way, could usefully replace part of a conventional pig diet the fact would deserve publicity so that the technique could be more widely adopted. If on the other hand it should prove to be of so little value that it does not repay the labour of collection, people should be advised not to waste their time."

Siriwardene, J.A. de, S.S.E. Ranawana and G.A. Piyasena, 1970 Study of the feeding value of Salvinia auriculata for growing pigs. Trop.Agric., Colombo, 126(1):31-4

Trials were carried out with crossbred pigs to measure weight gains when fed on a diet of Salvinia auriculata, compared with a grass, Brachiaria brizantha, each as a supplement to a basic ration of rice bran, maize and coconut meal. The pigs ate less of the Salvinia (0.76 kg daily) than the grass (1.5 kg). This was attributed both to the bulkiness of the fresh Salvinia and to its unpalatability. Dried Salvinia was offered to the pigs but they would not eat it at all. Thus the pigs made much less weight gain on Salvinia than on the grass. The authors concluded, therefore, that Salvinia is of no practical value in the feeding of pigs.

*Villadolid, D.V. and P.M. Bunag, 1953 New uses for water hyacinths. Philipp.Fish.Yearb., 1953:80-1, 241-2

The authors give details of a mixture, which includes water hyacinth, used by Malay farmers for pig food and which they say is also good for ducks and pond fish:

(i)	Rice middlings ('binlid')	100 kg
(ii)	Rice bran ('darak')	50 kg
(iii)	Salted fish of any cheap kind or fish meal	25 kg
(iv)	Water hyacinth chopped into small pieces	400 kg
(v)	Copra meal or cocoonut scrapings after oil has been extracted ('sapal')	50 kg
	Total:	625 kg

The greatest bulk of this feed formula is provided by the water hyacinth. The ingredients, with the exception of (v), are boiled in an iron vat or 'kawa' over an earthen oven and stirred over a slow fire until they are well mixed. After four hours of slow cooking they become a paste which is then mixed with 50 kg of cocoonut scrapings or copra meal previously soaked in water. The resulting broth is ready to be fed to the pigs when cooled. This mixture is good only for three days after which it will turn sour. Cooking brings out the appetising flavour from the ingredients and makes them more digestible for the pigs. It also removes the bitter and

raw taste in the water hyacinth. Frequency of cooking depends on the amount consumed by the pigs. For example, when they are six to eight months old they are given up to 10 kg of the broth at one time. It is best to prepare the broth once in two days.

This combination is economical and nourishing as well as filling and the pigs thrive best on it. From the list of components we find carbohydrates in (i), (ii) and (v), vitamin B in (ii), protein in (iii), (iv) and (v). The required minerals for rapid growth are amply supplied by water hyacinth. It will be observed that out of the 625 kg of foodstuffs 400 kg are represented by the hyacinth which can be had free. When cooked in a rice hull-fired oven, the fuel used can also be obtained free from rice mills.

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3. Poultry

*Bailey, T.A., 1965 Commercial possibilities of dehydrated aquatic plants. Proc.Annu.Meet. South.Weed Sci.Soc., 18:543-51

Bailey reports on the possibilities of extracting xanthophyll from Ceratophyllum sp. Elodea densa and Myriophyllum exalbescens. (The analyses of these plants are given in Chapter III.) He states:

"The feed ingredient industry is constantly alert for new ingredients or new additives which can improve the efficiency of the finished feed or can effect savings without detracting from the quality of the feed. In the above instance, we were impressed by the xanthophyll content of these dehydrated aquatic plants. Xanthophylls are oil-soluble carotenoid pigments found in some plants. There are many different xanthophylls. Some are effective in imparting a yellow colour to the skin of chickens and in darkening the yolk colour of eggs used mainly for the egg-breaking industry. Other xanthophylls are ineffective in this respect. Dr. J.B. Couch and associates of Texas A & M recently reported that xanthophyll in these aquatic plants gave good colouration to egg yolks, and rated xanthophyll in aquatic plants about equal to that in alfalfa meal in this respect. The most common feed ingredients supplying xanthophyll are yellow corn, dehydrated alfalfa meal and corn gluten meal.

"Although there is not much xanthophyll shortage here in the United States, many countries do not have much dehydrated alfalfa or other xanthophyll source ingredients available, and yet have a high demand for highly pigmented broilers and dark egg yolks. Thus there apparently exists a sizeable worldwide shortage of xanthophyll."

Bruhn, H.D., R.G. Koegel and D.F. Livermore, 1975 Utilization of aquatic vegetation. Paper presented to the Annual Meeting of the Northern Atlantic Region of the American Society of Agricultural Engineers, New York, 13 p.

Referring to the utilization of Myriophyllum spicatum and filamentous algae, the authors contend that research promises a considerable return from the recovery of protein and xanthophyll (used for egg yolk and poultry skin pigmentation). (From Weed Abstracts)

Creger, C.R., et al., The pigmenting value of aquatic flowering plants. Poultry Sci.,
1963 42:1262-3 (Abstr.)

A dehydrated blend of three species of flowering aquatic plants was analysed and found to contain 17.9% protein, 11% crude fibre,and 440 mg of xanthophyll per kg. Levels of 5, 10, 15, 20 and 25% of this blend produced NEPA numbers of 3, 4.5, 5.5, 6.3 and 6.8, respectively, when incorporated into milo-soybean oil meal basal diet and fed to laying hens. Levels of 10 and 20% of dehydrated alfalfa meal, which analysed 20% protein and 500 mg xanthophyll per kg, produced NEPA numbers of 4.75 and 6.1 under similar conditions. From these data it can be concluded that the naturally occurring xanthophylls found in a dehydrated blend of three species of flowering aquatic plants were biologically available and produced egg yolks of NEPA numbers similar to those which resulted from the feeding of approximately equivalent levels of xanthophyll from dehydrated alfalfa meal.

*Lange, S.R., The control of aquatic plants by commercial harvesting, processing and
1965 marketing. Proc.Annu.Meet.South.Weed Sci.Soc., 18:536-42

The author reports the harvesting of Myriophyllum, Elodea and Ceratophyllum in north eastern Texas. The weeds were processed through a conventional alfalfa (lucerne) dehydration mill to produce 40 t of dried meal. This was sent to Texas A & M University for a stock feeding programme which involved poultry, pigs and cattle. The results gave strong indication that the potential for commercial production and marketing lay in the direction of a poultry feed supplement for egg yolk and broiler pigmentation. This was based on xanthophyll values in excess of 660 mg/kg, protein in the 20% range, and a low fibre of 10-15%.

*Ling, S.W., Control of aquatic vegetation. In Lectures presented at the Third Inter-
1960 national Inland Fisheries Training Centre, Bogor, Indonesia, 31 October - 10 December 1955, conducted by the Government of Indonesia and FAO with the cooperation of IPFC. Vol.1. Rome, FAO, (3•23):12 p.

Small and tender plants such as Lemna and Wolffia are excellent as feed for ducks.

Little, E.C.S., The floating islands of Rawa Pening. PANS, 15(2):147-53
1969

The author refers to duck farming on the Rawa Pening lake in Central Java in Indonesia. The emergent grass Echinochloa stagnina, common in the shallow water of the lake, was readily grazed by flocks of ducks which pulled down the stalks to eat the seed heads.

Maciejewska-Potapczykowa, W., L. Konopska and E. Narzymska, Proteins in duckweed (Lemna
1970 minor). Acta Soc.Bot.Pol., 39(2):251-5

The authors state that water plants belonging to Lemnaceae such as Lemna, Spirodela and Wolffia are willingly eaten by poultry, particularly ducks.

Muzaffarov, A.M., T. Taubaev and M. Abdiev, (The utilization of duckweed for poultry
1968 feed). Uzb.Biol.Zh., 12(3):44-6 (in Russian)

In the summary of their paper the authors say that Lemna minor is rich in nutrients and vitamins. It contains 30-32% albumins and 30-35% starch. It is readily eaten by poultry with gain in weight. In the livers and egg yolks of poultry fed on L. minor the content of vitamin A and carotene was 2 to 2.3 times greater than that of the control birds.

Ross, E., Biological control of pond weeds with white Chinese geese. Hawaii Farm Sci.,
1971 20(2):11-2

On a fish pond heavily infested with Brachiaria mutica an attempt at control was made by releasing 5-week-old goslings. However the weed provided insufficient protein and carbohydrate with the result that the geese lost weight. Feeding daily with a food supplement prevented further losses. The geese thrived and made steady inroads into the B. mutica, and within 2½ years the pond was almost clear. (From Weed Abstracts)

*Smetana, P., Water hyacinth compared with elephant grass. Extract from report to the
1968 Government of Burma, by P. Smetana, FAO Poultry Expert, Burma. In Handbook of utilization of aquatic plants, edited by E.C.S. Little. Rome, FAO, Plant Production and Protection Division, PL:CP/20:51

The author briefly refers to the use of water hyacinth and elephant grass as green feed for poultry in Burma. Commenting on this, Mr. W.V. Thomann, poultry expert at FAO, Rome, in 1967, pointed out that water hyacinth, being high in carotene, intermediate in fibre, and low in protein, could be used as a valuable feed instead of being looked upon as a pest.

*Villadolid, D.V. and D.M. Bunag, New uses for water hyacinths. Philipp.Fish.Yearb.,
1953 1953:80-1

Around Laguna de Bay, Philippines, but especially in Pasig and Pateros, the water hyacinth is directly fed to ducks for their roughage requirement. The ducks readily consume the live plant leaving only the hard stems. (See also p. 94 for details of a food ration made with water hyacinth which the authors state is good for ducks.)

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4. Silage

*Agrupis, F.M., The value of water hyacinth as silage. Philipp.Agric., 37(1-2):50-6
1953

The author compared the value of silage made from water hyacinth with that from para grass (Panicum purpurascens). Two silos were filled with either of the test plants and a third with an equal mixture. Before packing carefully in the silos, bundles of the plants were dipped in a mixture of one part of molasses and four and a half parts of water. The tops of the silos were well covered to exclude air and then allowed to stand undisturbed for two months. The experiment was repeated. Red

Sindhi cows were used to test the palatability of the different kinds of silage. Analyses of the three kinds of silage are given in the following table:

Nutrient and mineral content	Para grass	Mixture of para grass and water hyacinth	Water hyacinth
	%	%	%
Moisture	77.94	82.33	90.65
Crude protein (N x 6.25)	1.57	1.02	0.85
Carbohydrates (N.F.E.)	9.16	7.48	3.93
Crude fats (ether extract)	1.22	1.56	0.39
Crude fibres	6.80	4.69	2.17
Ash	3.31	2.92	2.01
Calorific value for every 100 g	54.00	48.00	23.00
Calcium	0.36	0.38	0.28
Phosphorus	0.23	0.17	0.09

Agrupis reported: "In this experiment, the animals were reluctant to take the water hyacinth silage even after salt had been added. The feeding of water hyacinth was therefore discontinued and the silo containing it was closed. The mixture of para grass and water hyacinth was next fed to the cows. It was surprising to see the animals eat this kind of silage which also contained water hyacinth. After the animals had been fed this silage for six days, water hyacinth silage was tried again. This time the animals relished the feed. The water hyacinth in the mixture was probably the cause for the animals eating the pure water hyacinth silage later. The average consumption of para grass silage ranged from 9.52 to 13.52 kg, or an average of 11.52 kg; of the mixture of para grass and water hyacinth silage, 10.01 to 14.53 kg or an average of 12.27 kg; and of water hyacinth silage, 12.79 to 17.97 kg or an average of 15.38 kg."

"The colours of the different kinds of silage varied. Water hyacinth silage had the best colour; it was yellow or amber. Para grass silage was dull brown-yellow. The mixture of para grass and water hyacinth silage had a colour that was intermediate between the two."

Bagnall, L.O., J.A. Baldwin and J.F. Hentges, Processing and storage of water hyacinth
1974 silage. Hyacinth Control J., 12:73-9

Water hyacinth was harvested and chopped into 10-25 mm lengths. It was then dewatered by screw-pressing using either a 30-cm Vincent screw press or a portable 23-cm press. Operating pressures were 90-152 KN/m^2 at 15-50 rpm. Pressing was repeated two to three times as needed for the trials. Additives at various rates were either dried citrus pulp, standard cane molasses, yellow dent corn or dried water hyacinth. Various sized silos were used, up to a 3.7 x 12.2 m concrete tower. Run-off from the silos was collected and measured. The silage was tested and then fed to sheep and cattle. Tables are given showing the percentage of water expression with different pressures (45-74%), the contributions of dry matter from different additives, and the density shrinkage and losses to the silage from different treatments. The test animals rejected the plain chopped hyacinth silage but accepted the pressed material.

It was concluded that acceptable silage can be produced from water hyacinth by removing 50% or more of the water and adding free carbohydrates. Dried citrus pulp or cracked yellow dent corn at 2-4% are satisfactory additives. Standard cane molasses at 1% or less is not satisfactory as it did not affect the quality of the silage.

Baldwin, J.A., J.F. Hentges and L.O. Bagnall, Preservation and cattle acceptability of
1974 water hyacinth silage. Hyacinth Control J., 12:79-81

The water hyacinth silage most acceptable to cattle contained supplements of 4 kg dried citrus pulp, and 1 kg standard cane molasses as preservatives per 100 kg of chopped and pressed plant material. The silage with the lowest ash content (14.7%) was the most favoured. Yellow dent corn was also compared with dried citrus pulp, and at 4 kg/100 kg plant material was equally acceptable.

Baldwin, J.A., et al., Comparison of pangola grass and water hyacinth silages as diet
1975 for sheep. J.Anim.Sci., 40(5):968-71

Water hyacinth was compared with pangola grass (Digitaria decumbens) when made into silage as fodder for sheep. The pangola grass was harvested without wilting, chopped (1.6 cm pieces), and packed in tower silos 1.23 m x 2.46 m. The hyacinth silage was chopped (1.6 cm), pressed in a Vincent press (1.27 kg/cm^2, 49 rpm) to remove moisture, and similarly ensiled. Four kg of dried citrus pulp and 0.5 kg of sugar cane molasses were added per 100 kg of pressed plant material. Analyses of the two silages were tabulated (% dry matter):

Component	Pangola grass chopped	Water hyacinth chopped	Water hyacinth pressed
Organic matter	93.9	77.0	82.7
Ash	6.1	23.0	17.3
Crude protein	6.2	11.3	10.6
Calcium	0.46	2.5	2.2
Phosphorus	0.44	0.77	0.56
Magnesium	0.28	0.51	0.38
Potassium	1.12	7.03	4.15
Dry matter % wet weight	22.4	3.8	10.0

A further table of chemical composition of the two silages showed similar analyses except that the water hyacinth figures were again higher for crude protein and ash.

The wethers used for the tests ate more of the pangola grass silage. The digestibility of the dry matter, organic matter and crude protein of the pangola grass was higher than the hyacinth. The authors comment that more research is needed into water hyacinth silage and the mineral imbalances, especially the CA:P ratio, and the high K would need to be corrected.

Byron, H.T., et al., Organic acid preservation of water hyacinth silage. Hyacinth
1975 Control J., 13:64-6

Acetic acid, formic acid and a commercial product containing 80% propionic and 20% acetic acid by weight, were individually evaluated at high (0.5%) and low (0.25%) levels to determine their effect on ensilability of chopped, pressed water hyacinth, and voluntary intake by cattle of acid-treated water hyacinth silage. Preservation of ensiled water hyacinth as evaluated by silage acidity, temperature profile and degree of spoilage was acceptable for all acid treatments. Voluntary intake of silage treatments improved as lactic acid concentration increased and pH decreased. Treatment with high and low levels of a commercial product (containing 80% propionic acid and 20% acetic acid), and high formic acid were more acceptable to cattle than low formic acid, control, high acetic acid, and low acetic acid silage.

Chibbar, S.S. and G.D. Singh, Paddy straw and water hyacinth silage. Indian Farming, 1971 20(11):24-6

Paddy straw and water hyacinth can be mixed to form a valuable silage. Experiments are described in this paper.

After washing, the hyacinth was drained and then cut by chaff-cutter into 2.5-4 cm pieces. The paddy straw was similarly chopped, and mixed into the hyacinth at the rate of 1:4. Molasses diluted with water was added at the rate of 70 kg per tonne and evenly mixed in. The material was compacted into silos and covered with weighted polythene sheet. After four months the silage was analysed:

Silage	Dry matter	Crude protein	Ether extract	Crude fibre	Nitrogen free extract	Ash	Carbo-hydrates
Fresh	20.61	6.98	2.54	14.69	55.14	20.65	65.83
Residue	20.01	6.54	2.95	11.32	58.00	22.22	69.32

Average digestible crude protein (DCP) = 2.4%
Average total digestible nutrients (TDN) = 41.8%

Feeding trials with cows showed that the nutritive value of the silage was adequate for maintenance. But to meet full DCP and TDN requirements the authors recommend a supplement like groundnut cake or 1-2 kg of lucerne or berseem hay. They conclude that the straw and hyacinth silage could help to meet the unsatisfied demand in India for nutritious cattle fodder, and at the same time help to keep paddy fields and water channels clean of hitherto unwanted plant material. More milk, which is badly needed for poor people, would be produced.

Combs, G.E., J.F. Hentges and R.L. Shirley, Processed aquatic plants for animal 1973 nutrition. Annu.Res.Rep.Inst.Food Agric.Sci.Univ.Fla., 1973:81 (Abstr.)

Voluntary intake of water hyacinth by sheep and cattle was highest with treatments containing 4 kg dried citrus pulp and 1 kg sugar cane molasses per 100 kg hyacinth press residue; these treatments had the highest acidity, lowest ash and least surface spoilage. Both *in vivo* (sheep) and *in vitro* o.m. digestibilities of a land forage, pangola grass (*Digitaria decumbens*) were higher than for the best treatments of hyacinth silage. Preservation of hyacinth silage was satisfactory with formic, propionic and acetic acids and their mixtures as measured by acidity, temperature and spoilage. Acceptability of these treatments by cattle was highest with high lactic acid and low pH. These results indicate a potential value as ensiled ruminant animal feed for mechanically harvested and processed water hyacinths. (From Weed Abstracts)

Kiflewahid, B., Nutrient composition and digestibility of water hyacinth - by cattle. 1975 Diss.Abstr.Int., 36(12):5878-9

In trials using steers, silage containing 20% *Eichhornia crassipes* showed generally similar digestibility coefficients to that containing 20% cotton seed, and appeared to be suitable in cattle diets when supplemented. Structural organic components and *in vitro* digestibility of organic matter and dry matter of fresh and processed *E. crassipes* parts were examined in detail. (From Weed Abstracts)

Linn, J.G., et al., Nutritive value of dried or ensiled aquatic plants. 1. Chemical
1975 composition. J.Anim.Sci., 41(1):601-9

In this paper detailed analyses of 21 aquatic plants are given (see Chapter III). The authors concluded that such plants could be useful forages for ruminants, especially because many were high in protein and low in crude fibre thus indicating a high nutritive value. Also, estimates of hemicellulose, cellulose and lignin contents suggested that many of the plants should be highly digestible.

A fermentation study was carried out with a mixture of aquatic plants : 50% Myriophyllum exalbescens, 30% Ceratophyllum, 10% Potamogeton pectinatus and 5% Vallisneria (the remaining 5% was not identified). This was ensiled, on a laboratory scale, with different organic acids and additives of corn grain and chopped alfalfa. The silages were analysed and the detailed results tabulated. Conclusions were:

(i) Dry matter of aquatic plant silage and alfalfa silages were 33.3 and 32.3%, respectively.

(ii) All acid-treated silages were higher in protein than untreated, indicating less loss of proteins during ensilage.

(iii) Ash contents of all aquatic silages were high (average 47.5%), indicating soil contamination.

(iv) No large chemical differences, including organic content, were noted when 5% corn grain or 75% alfalfa was added to the aquatic plant silages.

(v) Formic acid was the most effective in reducing butyric acid formation.

(vi) Addition of alfalfa to sterilized aquatic plants produces more acceptable silage than when added to unsterilized aquatic plants.

Linn, J.G., et al., Nutritive value of dried or ensiled aquatic plants. 2. Digestibility
1975a by sheep. J.Anim.Sci., 41(1):610-5

The authors report on the digestibility to sheep of the same aquatic plants as tested in the paper referred to above, when dried or ensiled. It was found that dried Myriophyllum exalbescens and Potamogeton pectinatus were unpalatable (less than 600 g dry matter consumed daily) to lambs. Mixing an equal proportion of dehydrated alfalfa to either of these two species resulted in dry matter and crude protein digestibilities, as determined by difference, of 43.8 and 46.0% for M. exalbescens and 43.4 and 44.1% for P. pectinatus. Energy digestibility was higher for M. exalbescens (53.7%) than P. pectinatus (47.4%). Lambs fed on diets of ensiled aquatic plants, aquatic plants plus corn, or aquatic plants plus alfalfa silage, had dry matter digestibilities of 61.9 and 66.2%, respectively. Nitrogen and energy digestibilities of 61.9 and 66.2% were lower for lambs fed rations that contained aquatic plants than for lambs fed alfalfa silage or silage plus corn. Rumen fluid pH was higher, and molar percentages of acetic acid were lower, for lambs fed rations that contained aquatic plants than those fed alfalfa silage. Propionic acid was highest in rumen fluid from lambs fed the aquatic plant plus corn ration; thus a lower acetic : propionic ratio was observed for these lambs.

The results of this study suggest that palatability of aquatic plants may be a limiting factor in their use as a forage for ruminants. Drying or ensiling did not appear to be satisfactory procedures for improving palatability.

*Loosli, J.K., et al., The digestibility of water hyacinth (Eichhornia crassipes)
1954 silage by sheep. Philipp.Agric., 38(2-3):146-8

The authors prepared water hyacinth silage in a manner similar to that carried out by Agrupis (1953). This was fed ad lib. to sheep. They state: "On a dry basis the silage appears fairly nutritious. The sheep were unable to eat enough to maintain their weights unless a concentrate was also fed." They give three analyses of their water hyacinth silage as follows:

Moisture	Protein	Fat	Fibre	N.F.E.	Ash
93.73	0.84	0.17	1.34	2.65	1.27
88.24	1.12	0.14	2.21	6.31	1.98
87.63	1.05	0.14	2.46	6.21	2.51

A detailed table of digestion coefficients of the silage with and without added concentrate is also given.

They conclude: "On account of the low feeding value of water hyacinth silage, preparing it does not seem worthwhile, unless other feeds are scarce or very expensive. Of course, water hyacinth silage can be greatly improved in value by adding to it during ensiling nutritive feeds such as undiluted molasses, copra meal, and rice bran, but fermentation losses may be too great to make this procedure economically advisable. Perhaps a mixture of rice straw and water hyacinth would make a silage suitable for maintaining cattle or carabaos during periods of feed shortage."

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Fresh water hyacinth used as cattle fodder in the Sudan

Duck farming on Rawa Pening lake,
Central Java, Indonesia

Ducks controlling water hyacinth in borrow pit,
Bangkok, Thailand

VIII. FOOD FOR FISH AND AQUATIC ANIMALS

The ideal way to utilize aquatic weeds is to employ animals to harvest the plants by eating them and thus convert them into useful products, the only expense involved then being the periodic harvesting and processing of the animals. Herbivorous fish are obviously candidates for this task, as well as aquatic and herbivorous mammals and birds. Because of the attractiveness of this concept there is a considerable body of literature on the subject, especially on the white amur, also known as the Chinese grass carp, Ctenopharyngodon idella.

In the selected papers on grass carp summarized in this chapter, and in the review by Opuszyński (1972), are references to the remarkable capacity of this fish to eat aquatic weeds, its rapid growth, and the palatable and nutritious flesh it produces. Because it is herbivorous when mature, and eats a wide range of aquatic plants, it is easy to assume that the grass carp is potentially ideal as a method of both controlling and utilizing aquatic plants. Moreover, the difficulty of breeding the fish appears to reduce, but not eliminate, the possible hazards of introducing it into new areas. In spite of the advantages, great caution is being shown in its release into new habitats because there is still considerable doubt as to whether the carp might not profoundly disturb the aquatic environment, and especially other valuable species such as trout and other game fish, which may be adversely affected. An early but still useful review of observations on feeding habits of grass carp is given by Singh et al. (1967), and a bibliography on the grass carp published by FAO gives 243 references (Nair, 1968).

A more recent bibliography prepared by the Agricultural Research Council, Weed Research Organization, U.K. (1976) entitled "Selected references to herbivorous fish", contains 162 annotations.

The grass carp is a good example of the difficulties inherent in the use of aquatic animals: how to control what they eat and predict the effect they may have on the other organisms in the water. With birds (like ducks and geese) it is possible to control their activities to some degree, as can be done with domestic livestock. But careful introduction and restrictive measures are necessary in order to impose some degree of control on aquatic animals. This is the main disadvantage of biological control of plants by animals as distinct from mechanical harvesting or destruction by chemicals. Moreover, the use of animals may be unreliable because disease, climate, migration or other influences may reduce their activity when it is most needed.

The large aquatic mammal, the manatee, was suggested (Allsopp, 1960, 1961) as a potential method of aquatic weed control following its successful use in Guyana. The idea aroused world-wide interest, but this flagged when the scarcity of the manatee became apparent, and the difficulties involved in its management were described (Bertram and Bertram, 1962).

Shell (1962) describes trials in ponds in the U.S.A. with a strain of the common carp (Cyprinus carpio) and three species of tilapia, T. nilotica, T. mossambica and T. melanopleura. The author suggests that control of aquatic weeds by the carp may be as much due to the fish dislodging the plants while looking for food, and covering algae with mud, as actually eating them. Tilapia in the U.S.A. are useful for eating weeds but are vulnerable to cold and predators. T. melanopleura was probably the most successful. The general conclusion from the trials was that while the fish tested may be of some value in controlling aquatic weeds they were not the total answer to the problem.

Bennett (1974) has given a brief review on the use of fish, including grass carp, tilapia and two fish both known as silver dollar, Metynnis roosevelti and Mylossoma argenteum. He comments that the dual role of fish as weed control agents and as a source of protein for human or animal food gives added initiative for investigating the more promising species. However, there is considerable concern over the possible detrimental

effects on the various components of the ecosystem that may follow the introduction of exotic fish. The author also reviews briefly the limitations of the manatee and the coypu.

No comprehensive review of the literature on the use of fish and aquatic animals appears to have yet been published.

However, in the U.S. National Academy of Sciences publication (1976) on "Making aquatic weeds useful: some perspectives for developing countries", Part I is devoted to the subject. The chapter headings are: grass carp (14 references); other herbivorous fish (12 references); manatees (four references); ducks, geese, and swans (two references); other herbivorous animals, with sections on water buffalo (one reference) and the rodents Capybara (one reference) and Nutria (four references); crayfish (11 references). The crayfish is an unusual animal as a potentially lucrative exploiter of aquatic vegetation. It is pointed out that "crayfish should be thought of more in terms of an available crop associated with aquatic weeds, not as a weed-control agent."

The red crayfish, Procambrus clarkii, which is widely farmed in Louisiana, U.S.A., is described as an omnivorous type which does not prefer plants "but will consume all vegetation available - including water hyacinth - if there is nothing better to eat (a situation that commonly occurs when their populations are very dense)". There are many hazards associated with crayfish and the potential impact of any crayfish which it is intended to introduce must be thoroughly studied under strict security before they are released into an aquatic environment. A world-wide search for edible size herbivorous crayfish is needed. Among the species which exist some are likely to prove good food and valuable aquatic weed control agents. The food habits of crayfish, techniques for rearing and harvesting, and the effectiveness of crayfish in removing vegetation under different aquatic situations, such as rice and taro paddies, waterways and reservoirs, all need thorough review and analysis. Only a part of the crayfish is eaten, most of the body being discarded. The carcase is high in calcium and nitrogen so research is needed to determine the usefulness of the carcase for fertilizer and animal feed.

The information given by the National Academy of Sciences is succinct, authoritative and well illustrated. The book is recent and readily available.

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Achmad, S., 1971 Problems and control of aquatic weeds in Indonesian open waters. In Tropical weeds; some problems, biology and control. Proceedings of the 1st Indonesian Weed Science Conference, Bogor. Biotrop.Bull., (2):107-13

The author points out that the presence of a certain amount of aquatic plants can stabilize fish production. A balanced population of predators and forage fish cannot be maintained if there are no hiding places for the fingerlings. A list of fishes, in addition to grass carp, which feed on aquatic plants in Indonesia is given as follows (local name in brackets):

Leptoharbus hoeveni	(djelawat)
Puntius javanicus	(tawes)
Puntius bramoides	(lelawak)
Osteochilus melanopleura	(ketabau)
Cyclocheilichthyes apogon	(seren)
Tilapia mossambica	(mudjair)

Plants preferred by such fish include Ipomoea aquatica, Azolla spp., Salvinia spp., Hydrilla spp. and Pistia stratiotes.

Adams, A.E. and V. Tifolko, A progress report on the introduction of grass carp
1970 (Ctenopharyngodon idella) in Fiji. Fiji Agric.J., 32(2):43-6

Hydrilla verticillata is a serious weed in rivers in Fiji. Grass carp were imported from Malaysia as fingerlings and fed on the weed in a pond, and released into a netted portion of the Rewa river. Weight increased from 9.75 g in December 1968 to 3 069 g (length 56 cm) in April 1970. This weight gain was noted as being much higher than those recorded in Malaysia, China, Russia and various European countries. It was concluded that grass carp are able to control H. verticillata but that large-scale introduction of the fish to do this was dependent on the successful development in Fiji of induced breeding.

Ahling, B. and A. Jernelöv, Weed control with grass carp in Lake Ösbysjön. Rep.Swed.
1971 Water Air Pollut.Res.Lab., (B94a):24 p. Issued also in Vatten, 27(2):253-64

The authors describe an experiment to control Myriophyllum verticillatum in a lake in Sweden with grass carp. The area of the lake was 4.6 ha and contained about 16 tonnes (dry weight) of the weed. In May, 250 grass carp, average weight 380 g, were introduced. After 100 days they had increased in weight to about 1 kg average, and had consumed about half of the weed. At the same time some Potamogeton natans was eliminated, while Nymphaea alba, Typha angustifolia and Phragmites sp. were largely unaffected. A curious feature was that the Myriophyllum reduction was uneven, some areas being cleared and others apparently unchanged. The clearance was more pronounced in deeper water. There was a slight increase in plankton but no effect on turbidity.

Blackburn, R.D. and D.L. Sutton, Growth of white amur (Ctenopharyngodon idella) on
1971 selected species of aquatic plants. Proc.Eur.Weed Res.Counc.Int.Symp.Aquat. Weeds, 3:87-93

Tests with grass carp in tanks showed that the fish gained more weight on a diet of fresh Najas guadalupensis and Hydrilla verticillata than on a dried fish food diet. Contrary to the observations of other authors cited in this chapter grass carp were observed to eat water hyacinth. The small fish ate only the roots and did not grow so fast as the large fish which ate both leaves and roots. (From Weed Abstracts)

Chapman, V.J. and B.J. Coffey, Experiments with grass carp in controlling exotic Macro-
1971 phytes in New Zealand. Hidrobiologia, Bucharest, 12:313-23

The authors review the introduction and spread in New Zealand of the submerged aquatic weeds Lagarosiphon major, Ceratophyllum demersum, Egeria densa and Elodea canadensis. Methods of control are discussed including possible utilization by harvesting for stock food. Though harvesting was considered practicable the use of the plants as fodder was believed to be unsuitable because of the content of arsenic accumulated by the plants from the thermal waters that enter the lakes. Arsenic in amounts of 35-75 ppm dry weight are common, and extreme values up to 2 000 ppm have been recorded. The alternative possibility of the use of grass carp was investigated as considered more promising, so a few fish were imported from Malaysia.

Trials showed that carp would eat the problem weeds, though not uniformly. The order of preference was Egeria, Lagarosiphon, Ceratophyllum. Further trials were carried out which included, in addition, 18 other aquatic plants. The order of preference of these plants is listed. It was noted that plants of the same species from different sources varied apparently in their palatability. Lagarosiphon, especially the

young tips, was preferred to Egeria, which was superior to older Lagarosiphon, the tough stems of which were rejected. Other plants rejected were Typha angustifolia, Myriophyllum brasiliense and the rootstock of Vallisneria gigantea, and, surprisingly, pasture grasses. The authors observe that grass carp have the capacity to survive periods of starvation by losing weight. Therefore in the field it may be better to overstock mildly rather than understock. Arsenic accumulation in carp after feeding on Lagarosiphon from arsenic-rich water was recorded.

Denike, T.J. and R.W. Geiger, 1974 The utilization of Chara in water management. Hyacinth Control J., 12:18-20

Chara spp. are considered as useful aquatic plants because they provide excellent habitats for fish; their fragile stems do not impede boats, and the plants maintain environmental balance. But the Chara requires control and can, in shallow water, become undesirable. With the use of suitable herbicides unwanted weeds such as Hydrilla, Najas and Utricularia can be suppressed and thus encourage the growth of Chara. Some species of Chara present in Florida, U.S.A., are: C. vulgaris, C. schweinitzii, C. lornemanni, C. foliosa and C. fragilis.

Hill, H.R. and R.E. Rintz, 1972 Observations of declining water lettuce populations in Lake Izabal, Guatemala. Proc.Annu.Meet.South.Weed Sci.Soc., 25:374-80

Turtles are reported to feed on Pistia stratiotes in Lake Izabal. The authors cite reports of the herbivorous turtles, Dermatemys and Pseudemys, being caught by local inhabitants for food. It is supposed that turtle feeding could account for observed root damage to Pistia plants.

*Hora, S.L., 1951 The water hyacinth problem and pig farming. Sci.Cult., 17(6):231-2

The author describes the water hyacinth-pig-fish-human cycle adopted as a farming system in ponds in Malaya.

"The fish caught from the pond were Trichogaster pectoralis (corresponding to Kholisha of Bengal) and Clarias (Magur of Bengal). We were informed that other varieties of Jiol Machh (Live Fish, species of Ophiocephalus) were also present. The pond was of a small size, probably less than 2 000 sq. feet [180 m²] in area, but it was thickly covered with a luxuriant growth of water hyacinth. The water was dirty and thick and full of sludge matter. There was a small clearance in the middle where the net for catching fish was used. On one side of the pond, there was a piggery, the washings from which were being drained into the pond. Besides there were overhanging latrines over the pond. The primary object of heavily manuring the pond was to keep going the luxuriant growth of water hyacinth which was being harvested every day for use as pig fodder. We saw it being cooked with oil cake and other ingredients of the usual Chinese pig-feed. The pigs are kept in enclosures and do not roam about and feed on dirty matter as is seen in certain Indian villages.

"Fish taken out from such heavily polluted ponds are kept in tubs or small masonry pits for a few days and fed on wholesome food. The fishes thus get cleaned of the sludge matter and gain excellent flavour and taste."

The paper urges the introduction of similar methods into Bengal, especially in sewage-irrigated areas near Calcutta. The author states that the use of water hyacinth for pig fodder and the production of live fish, so highly valued in Bengal for their nutritional qualities, would change the weed from a pest to a blessing.

Legner, E.F., et al., Biological aquatic weed control by fish in the lower Sonoran Desert
1975 of California. Calif.Agric., 29(11):8-10

Irrigation channels heavily infested with Potamogeton pectinatus, Myriophyllum spicatum, Najas guadalupensis and Chara sp. were attacked by the introduction of the fish Tilapia hornorum, T. mossambica and T. zillii. In one trial the T. zillii were introduced at the rate of 4 700/ha. Within four months almost all of the weeds had been disposed of. The fish numbers during this time had increased to 11 000/ha. An important observation in this and other trials was that the large rise in tilapia population also increased the game fish numbers. Tilapia was found in the stomachs of these fish (largemouth bass) indicating that the tilapia play an important role in the game fish food chain. Overwintering survival of T. mossambica and T. zillii is poor because they are then lethargic and are taken by predators, so that continuous annual stocking is essential for maximum biological control of the aquatic plants. The tilapia breed and grow fast if the water temperature is around 21°C. The lower critical temperature is about 10°C. Tilapia have the additional advantage of reducing mosquito breeding habitats. Because of the successful trials it is expected that the use of tilapia will be extended over most of the region of Southern California.

*Le Mare, D.W., Pig rearing, fish farming and vegetable growing. Malay.Agric.J., 35(3):
1952 156-66

The paper describes a fish farm in Malaysia about 1 ha in area, consisting of eight ponds about 1 m in depth and supplied with water from a stream which was diverted to flow through piggeries. Six ponds were stocked in December 1949 with 16 500 Tilapia mossambica, and four species of carp (Ctenopharyngodon idella, Aristichthys nobilis, Hypophthalmichthys molitrix and Cyprinus carpio) were placed in the other two ponds in February 1950.

"The fish were, at first, irregularly fed with rice bran. In April 1950, pig manure became available from the pig-fattening section and this rapidly caused a luxuriant growth of algae, diatoms and crustacea (all microscopic life) on which the fish fed, and feeding of the fish with bran was stopped. At the same time, kangkong (Ipomoea reptans) was introduced into the ponds. This plant grew well and within six weeks of planting it was possible to harvest the vegetable daily as pig fodder. It is important to note that the Health Department have kept a careful watch on the ponds and, because the young of the fish Tilapia are effective larval feeders, there has been no undue breeding of mosquitoes in the roots of the kangkong."

Liang, J.K. and R.T. Lovell, Nutritional value of water hyacinth in channel catfish
1971 feeds. Hyacinth Control J., 9(1):40-4

A series of feeding trials were carried out to find the usefulness of Eichhornia crassipes (water hyacinth), Justicia americana, and Alternanthera philoxeroides as food for fingerling channel catfish (Ictalurus punctatus). The plant material was pressed to extract protein in the expressed liquid which was then separated to prepare a dry concentrate. This was fed in increasing amounts until it became 40% of the fish diet. J. americana proved the most palatable, followed by water hyacinth, then A. philoxeroides. It was found that the most favourable use of water hyacinth was as a supplement to vitamin-deficient diets when, if added at the rate of 5-10%, it increased growth and reduced mortality of the fingerlings. The water hyacinth meal in these respects was better than commercial alfalfa meal, and thus it could be used as a replacement for alfalfa when it is known that alfalfa meal has a value in these feeds.

*Ling, S.W., 1960 Control of aquatic vegetation. In Lectures presented at the Third International Inland Fisheries Training Centre, Bogor, Indonesia, 31 October - 10 December 1955, conducted by the Government of Indonesia and FAO with the cooperation of IPFC. Vol.1. Rome, FAO (3·23):12 p.

"Aquatic plants are so important as fish food that, in China and other countries where herbivorous fish are stocked and cultured in combination with other non-predatory species, fish farmers make special efforts to promote the growth of suitable kinds. It is therefore to be stressed that measures for the control of aquatic plants are warranted only when the growth of such plants has become so excessive as to interfere with the desired fisheries production and management."

Small and tender plants such as Lemna and Wolffia are excellent feed for certain kinds of fish. Salvinia may be collected in the autumn for grass carp. In Thailand grass carp will eat young shoots of Typha, Cyperus and Nymphaea and roots and young leaves of Pistia and Eichhornia. In Indonesia lakes densely covered with Hydrilla, Ceratophyllum, Ipomoea, Potamogeton, etc. have been converted to highly productive waters by the plant-eating fish Puntius javanicus and Trichogaster pectoralis.

McVea, C. and C.E. Boyd, 1975 Effects of waterhyacinth cover on water chemistry, phytoplankton and fish in ponds. J.Environ.Qual., 4(3):375-8

Water hyacinth growing on ponds stocked with the fish Tilapia aurea decreased phytoplankton production by shading and by removal of phosphorus from the water. When hyacinth had 25% cover of the water the dissolved oxygen was less than when the cover was smaller but there was still enough oxygen for survival and growth of fish. Reduction of phytoplankton progressively lowered the numbers of fish down to 5% water hyacinth cover, after which the effect on the fish could not be measured.

Mehta, I. and R.K. Sharma, 1972 Control of aquatic weeds by the white amur in Rajasthan, India. Hyacinth Control J., 10:16-9

Grass carp is reported as a voracious feeder of Najas foveolata, Chara sp., Vallisneria spiralis, Potamogeton nodosus, P. pectinatus, P. perfoliatus and Hydrilla verticillata. Fish weighing about 65 g preferred Chara sp., N. foveolata and V. spiralis. Larger fish (200 g) preferred P. pectinatus, P. nodosus, V. spiralis and N. foveolata, and only ate small amounts of Hydrilla sp., P. perfoliatus and Typha sp. However, large fish may flourish on these weeds and may be able to chew leaves of tough plants and fibrous grasses. The observations on grass carp to date are most favourable and show how useful they can be in place of herbicides. More information is needed on best stocking rates. (From author's summary)

Mitchell, C., 1977 The use of carp for submerged weed control. Proc.N.Z.Weed Pest Control Conf., 30:145-8

A lake in the North Island of New Zealand, heavily infested with Egeria densa, was divided by a net and grass carp were introduced at the rate of 22/ha to one half of the lake. A year later it was found that the carp had severely grazed a band of rushes (Eleocharis sphacelata) along the margin. The Egeria had been largely ignored. It was concluded that the carp stocking rate was too low, so much higher rates are to be tried in order to force the carp to eat the Egeria.

Opoku, A.K. and P.C. Pierce, 1971 Summary of results for a fishing strip clearing programme conducted at Volta Lake during 1970-71. In Report of the 4th Annual Meeting of the National Weed Committee for Ghana. Akosombo, Ghana, Volta River Authority, pp. 21-8

The authors discuss the problems related to fishing as a result of the growth of the emergent plants Vossia cuspidata, Polygonum senegalense and Alternanthera sessilis along the margin of Lake Volta. They point out that the aquatic plant population is beneficial as it provides food and shelter for fish, but the weeds also interfere with fishing and harbour the snail vectors for the disease bilharzia. They have considered the introduction of grass carp but regard it as unlikely to be useful against coarse emergent plants such as Vossia. Control by herbicides was not practicable, so clearance for fishing is being done by cutting and burning.

Opuszyński, K., 1972 The use of phytophagous fish to control aquatic plants. Aquaculture, 1(1):61-74

The paper gives a brief reference to silver carp but is mainly concerned with grass carp in Poland.

Silver carp (Hypophthalmichthys molitrix) grows up to about 1 m in length and a weight of 20 kg. It has dense gill rakers which enable it to filter plankton of more than 8 µm in diameter. The fish feed mainly on phytoplankton but can also take zooplankton. In pond trials near Warsaw it was found that when silver carp were present algal numbers increased. The reason for this was not understood. Possibilities were that numbers of young algae were encouraged to form by the carp eating the larger ones, or by reducing those zooplankton which also eat algae.

The biology of the grass carp and a wide range of observations and opinions on its diet are reviewed. They are warm-water fish, the upper lethal temperature for fry being 38-39°C, but they can winter at 1-2°C. They have low oxygen requirements, the lethal level for fry being 0.32-0.60 mg/litre. Sexual maturity depends on latitude. In China it is at 4-5 years, in central Europe 6-7 years, and in Moscow, U.S.S.R., 10 years. The eggs are semipelagic and develop while carried along with the river current. Grass carp are suitable for sport fishing and may be caught with plant, animal or spinning bait. The flesh is palatable.

When the fry are 30-40 mm in length they feed on zooplankton and some Chironomid larvae, but as they grow bigger they feed increasingly on macroflora. In fish over 16 g animal food represented less than 1% of all nutrients. The author cites Chinese reports that pond-cultured grass carp are omnivorous, including in their diet small fish and insects. As the fish grow they eat different plants. Initially these are filamentous algae, e.g. Fontinalis sp., Chara and small species of flower-bearing plants such as Lemna sp., Potamogeton pectinatus and Elodea canadensis. Fish weighing more than 250 g also eat emergent plants such as Schoenoplectus lacustris, Sagittaria sagittifolia, leaves and shoots of Phragmites communis and Glyceria aquatica. Young fish require more food per unit of body weight increase (food coefficients 92-78) compared with older ones (36-35). Animal protein is apparently essential in the diet but the quantity needed seems to decrease with growth.

In general the food preferred is soft submerged plants. In some instances the emergent Typha has been taken by breaking the base of the shoot and then eating all of it. One report states that Typha and Phragmites over 1 m tall are not eaten. Variation in consumption of filamentous algae has also been observed. In one case, where carp were exposed to a massive bloom, only 9% was found to be in their stomachs compared with 72% of macroflora, indicating a clear preference for the larger plants. When fish fodder is added to ponds the carp will take some but most of their food continues to be plants.

High temperatures increase feeding rates, rising to a maximum at 33°C, which is close to the lethal temperature. Daily food consumption is about 50% of body weight at 20°C rising to 100-120% at 22-23°C. Temperature variations are believed to affect food selection; at the higher temperatures the carp will eat harder plants like Typha and Phragmites. It is this characteristic that makes grass carp suitable for stocking in ponds heated by the cooling water from power stations, where the high temperature also encourages excessive growth of aquatic plants. Two species of plants observed to be reluctantly eaten by grass carp, even in heated waters, are Nuphar luteum and Najas sp.

In the moderate temperatures of north-east and middle Europe it seems unlikely that grass carp can be relied on for efficient weed control unless large numbers of big fish were used. But this is not considered economically justified. However grass carp might be useful adjuncts to regular mechanical or chemical methods of control.

The disturbing consequences on the conditions in a water body due to the introduction of grass carp are discussed. Many fish lay their eggs on aquatic plants so that the wholesale destruction of these plants by carp would alter the species composition of fish. The carp have strong masticating teeth so that their food becomes highly disintegrated, also the assimilation of food in the carp is extremely low (only 20%). This can result in large quantities of highly disintegrated and only partly digested plant mass. Also, carp excrement is easily decomposed by micro-organisms. All this may induce an intensive fertilization of the water resulting in a change from predominantly large aquatic plants to an undesirable situation such as an algal bloom.

Another feature of grass carp feeding is the turbidity of the water they cause by damage to plant roots. Many more plants are destroyed by grass carp than are eaten because of their habit of tearing out plant segments from the bottom and eating only a portion at the base. This has been observed with Glyceria aquatica which is particularly vulnerable because of a weak rooting system.

Piña, R., 1974 Las carpas contra el lirio. (Carp against water hyacinth). Tec.Pesq., 7(80): 12-3

In an attempt to control water hyacinth in the lake formed by the Endho dam in Mexico, one million grass carp fingerlings were released. The problems of maintaining an optimum carp population and the need for supplementary mechanical control methods are discussed. (From Weed Abstracts)

*Singh, S.B., 1963 Preliminary experiments on the relative manurial values of some aquatic weeds as composts. Proc.IPFC, 10(2):141-5

The author describes the composting of various aquatic weeds in India (see Chapter IX). He mentions the judicious use of these composts for the manuring of fish ponds.

Singh, S.B., et al., 1967 Efficiency of grass carp in controlling and utilizing aquatic weeds in India. Proc.IPFC, 12(2):220-35 (1966)

The feeding habits and preferences of grass carp introduced into ponds are recorded, and also the amount of plants eaten and the weight gains of the fish. Tabulated information is given on the stocking rate and size of fish and their feeding rate.

The authors list 17 plants the carp readily controlled, and five which were less readily taken. The fish did not feed actively on Eichhornia crassipes (water hyacinth) Pistia, Colocasia antiquorum, Nymphoides or Nymphaea. When only water hyacinth, Pistia and Colocasia were available the fish lost condition.

Sirenko, L.A., (Algal blooms of water). Kiev, Naukova Dumka, 268 p. (in Russian)
1969

This book on blue-green algae contains a section on their effect on fish. (From Weed Abstracts)

Stott, B. and L.D. Orr, Estimating the amount of aquatic weed consumed by grass carp.
1970 Prog.Fish-Cult., 32(1):51-4

In feeding experiments with grass carp in the United Kingdom the authors determined that if the fish had a diet of about 66% Elodea canadensis and 33% Myriophyllum sp., about 10 tonnes of fresh weed would produce about 100 kg of fish. The Kcal content/g was 0.345 for Elodea and 0.552 for Myriophyllum. They cite typical productivity of submerged macrophytes in temperate zones as 2-7 tonnes (dry weight)/ha/annum. This corresponds to the amount measured of Elodea and Myriophyllum at 17-59 tonnes fresh weight/ha/annum.

*Villadolid, D.V. and D.M. Bunag, New uses for water hyacinths. Philipp.Fish.Yearb.,
1953 1953:80-1, 241-2

The authors describe a variety of uses for water hyacinth in the Philippines, including details of its use for fish and pig feed.

"Some of our own fishpond operators, especially in Bulacan and Pampanga, have started to use the water hyacinth as supplementary food for bangos /milkfish, Chanos chanos/. This water plant is carried down the rivers of the swamplands in great quantities especially during the rainy season. It is stopped by bamboo floating barriers in front of the ponds and thrown high on the dikes every week. Then it is either stored for future use or piled immediately inside the ponds. In two or three days the piles of dry water hyacinths ferment and the bangos start to feed on them greedily.

"In the Minalin and Guagua area in Pampanga, pond operators have shortened the conversion process. They pile the fresh water hyacinths in the pond and cover them with a layer of mud. In a few days the pile rots and the fish begin to feed on the decaying weed."

Drying water hyacinth in the sun greatly increases the feed value per unit weight or volume of the plant. It is in this hay-like form that the hyacinth is recommended for use as a feed base, or a feed supplement, for fish.

For details of a feed mixture using water hyacinth given to pigs and fish by Malay farmers see Chapter VII.

*Zobairi, A.R.K., Manuring of fish ponds. Agric.Pak., 10(1):125-38
1959

The author describes an unusual way to utilise water hyacinth for fish culture. After making the hyacinth into compost it is scattered into fish ponds as fertilizer. Alternatively, the hyacinth is burnt to ash. The ash is then mixed with superphosphate at a ratio of 5:1 and then scattered over the surface of the pond at a rate of 920 kg/ha. The paper recommends weekly treatment until a dense bloom of zooplankton is formed. A further variation, recommended as the best, is to apply the fertilizer to the pond bed when it is dry in heaps or rows at the rate of 1-1.5 tonnes/ha and let the pond fill during the monsoon.

Zolotova, Z.K., 1970 Biological weed control in irrigation channels with the aid of grass carp. Sb.Nauchno-Issled.Rabot Vses.Nauchno-Issled-Inst.Prudov.Rybn.Khoz., 1970(4):112-26 (in Russian)

A canal with 46% infestation of emergent weeds was stocked with yearling grass carp at the rate of 5 400 fish/ha (250 kg/ha). Within two months the weeds had been reduced by 66%, mainly at the expense of Glyceria maxima, Leersia oryzoides, Beckmannia eruciformis and Carex riparia. Soft vegetation including Lemna minor and Salvinia natans was almost completely consumed. Typha latifolia (weighing 5.5 kg/m^2) was eliminated. Established reeds and Typha angustifolia were not taken by the young fish but they did eat new shoots as they emerged and thus arrested the spread of the plants. When the preferred plants were all consumed the carp fed on the decomposing stalks of T. latifolia, rhizomes of Phragmites communis, seeds of Typha spp. and roots of bank grasses. It was concluded that the grass carp, at 254 kg/ha, had consumed 15 700 kg of plant material per hectare within two months. (From Weed Abstracts)

Zolotova, Z.K. and L.V. Khromov, 1970 The weeding role of grass carp. Rybovod.Rybolov., 1970(4):8 (in Russian)

A heavily weeded pond was stocked with yearling carp at the rate of 1 250 fish/ha (188 kg/ha). Within 70 days the fish had cleared the pond of weeds totalling 16.2 t/ha. First attacked was the soft vegetation and a thick carpet of Carex riparia on the pond bottom, most of which was removed within a month. Next eaten was Sparganium spp. leaving fibrous vegetation dominated by Scirpus tabernaemontani, Typha latifolia, T. angustifolia and Phragmites communis. The fish then attacked these plants and broke down Scirpus spp 3 m high and chewed off P. communis at the base, consuming also the rhizomes. (From Weed Abstracts)

Anon., 1971 Use grass carp for weed control. Indian Farming, 21(5):45-7

The paper reports the introduction in 1959 of grass carp and its successful induced breeding and distribution in India. "The fish from 25-mm size starts feeding on minute floating plants such as Wolffia and as it grows it feeds on Lemna, Spirodela and Azolla, and cut bits of submerged weeds such as Hydrilla, Najas, etc., as the size of its mouth increases. Fish of about 100 g size can be used to control most of the common water weeds in small farm ponds, if free from predators. Bigger fish of 0.5-1 kg can be employed to control weeds in larger waters.

The submerged weeds preferred by grass carp are Hydrilla, Najas, Ceratophyllum, Potamogeton, Utricularia and Myriophyllum. The fish will also control Ottelia, Nechamandra, Vallisneria, Trapa, Limnophila and Salvinia (to some extent). However, water hyacinth and Pistia are not completely consumed.

For control of floating weeds grass carp of about 10 cm length (about 15 g) are stocked at 1 000-2 000/ha according to weed density. For other weeds use fish of about 20-30 cm (100-250 g) and stocked at 200-1 000/ha. Regular inspections are needed to determine whether control is proceeding satisfactorily. If not more fish can be added. After the weed has been cleared the fish may be carefully netted out of the water and transferred for use elsewhere. As grass carp is good to eat, and easily caught by angling, precautions against poaching are necessary. If predatory fishes are present then the grass carp should be at least 1 kg in weight before being introduced."
The paper goes on to describe methods of breeding and rearing the carp.

IX. FERTILIZER, COMPOST, MULCHING AND WEED CONTROL

The use of the decayed tissues of unwanted plants to provide nutrients for crops is a crude but effective way of exploiting weeds and is a simpler technique than any of the other alternatives available. Aquatic plants dragged from their environment to rot on dry land have the advantage that their seeds or vegetative parts do not present any risk of competing with the crop, but this involves considerable labour (as discussed in Chapter IV on harvesting). In areas where water weeds cause the greatest difficulty labour may be relatively cheap and the inducement to use the weeds enhanced by the cost and scarcity of artificial fertilizers, yet it is not universally common for poor farmers near large areas of aquatic weeds to exploit this resource. Kamal and Little (1970) illustrate the struggle of a gardener working on the banks of the Nile ignoring the vast resources of water hyacinth nearby and available for the taking.

Clearly the best use of aquatic weeds for horticulture would be to apply them as a thick layer on the soil to suppress weeds and conserve moisture. They could be used either during a fallow or as a mulch for a growing crop. When decay had eventually reduced the effectiveness of the mulch then the residues could be incorporated into the soil to add organic matter and nutrients.

Where the crop is distant from the weed source then, if possible, the weeds should be allowed to dry on the bank in order to minimize labour and transport costs; or the weeds could be composted, and when the process had been completed the much less bulky finished product could be transported. A further alternative, discussed in some of the papers in this chapter, is to burn the dried weeds and use the ash residue which would contain most of the minerals, except N, and weigh a small fraction of the original wet weed. This is a difficult operation in other than exceptionally dry countries or seasons when complete desiccation of the plants by solar heat is possible. An advantage of this procedure is that it minimizes the risk of transporting viable portions of any weed into regions so far uninfested.

The papers that follow discuss all these aspects of the use of aquatic plants for crop improvement.

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Abdalla, A.A. and A.T. Abdel Hafeez, Some aspects of utilization of water hyacinth
1969 (Eichhornia crassipes). PANS, 15(2):204-7

The authors carried out experiments in the Sudan with the use of water hyacinth as a mulch to suppress nutsedge, Cyperus rotundus. Using plots 3 m x 3.7 m, records were made of the effect of three rates of mulching on weed suppression. The mulch was kept in position for three weeks after which tubers of the sedge were taken from each plot and the time taken to sprout, as well as the growth rate, measured. In addition, the effect on retention of moisture in the soil as a result of the mulch was measured at three soil depths. The results are tabulated below:

Water hyacinth mulch tonnes/ha	Days to 50% tuber sprouting	Growth rate mm/day	Soil moisture %		
			Surface 0-13 cm	15 cm deep	30 cm deep
Nil	6.5	5.2	14.8	15.0	21.1
18	6.5	5.0	17.3	20.9	22.3
36	8	3.1	22.4	22.4	23.9
54	9	3.0	22.1	25.9	26.2

The authors conclude that the use of a water hyacinth mulch can be effective in controlling Cyperus rotundus and also in substantially conserving soil moisture. (See also Hafeez, 1975.)

*Basak, M.N., Water hyacinth compost. Alipore, West Bengal Govt. Press 1948

The author begins by discussing the burning of water hyacinth to ash for fertilizer use in Bengal. He rejects this because of the loss of valuable nitrogen and organic matter, the labour and difficulty of drying the plant, especially in wet weather, and the difficulty of storing and bagging the ash. He advocates the making of water hyacinth compost, which he says is "four times richer than farmyard manure and is less than the usual price of the latter." He considers that where labour is cheap mechanical harvesting is unnecessary and that the value of the compost will more than pay for the cost of making it.

"Floating masses of water hyacinth were easily drifted to the edge of the embankments by towing round a piece of rope or by the help of a boat; this minimised labour and difficulty of transport. Bunches of plants were then picked up from water by hand and spread immediately (without drying) on a square (10' x 10') [3 x 3 m], rectangular or circular plot (5 feet [1.5 m] in diameter) of plain high land, uniformly and loosely into a 1-foot [0.3 m] layer; care was taken to prevent any trampling or pressing of the heap. On the water hyacinth layer was placed a thin layer (1" to 2") [2.5-5.0 cm] of undiluted cowdung, alone or mixed with a little canal mud, urine earth or prepared compost. If cowdung or urine earth was not easily available in the area, as heppened when the centre was far away from habitations, the addition of the above materials also helped decomposition. Cattle dung and urine earth which act as valuable "starters" are always preferable for they not only enhance decomposition through necessary supply of suitable bacterial inoculum but enrich the final product by incorporation of additional nitrogen. A second 1-foot [0.3 m] layer of water hyacinth was similarly built up on the first with a thin layer of cowdung on it and the process repeated till the heap rose to about 6 ft [1.8 m]. The topmost layer of water hyacinth was built up in the shape of a dome and the top was plastered with cowdung and canal mud to prevent any subsequent intrusion of rain water into compost heaps.

"Previous drying of green water hyacinth and then moistening it with a slurry of cowdung and water (1:10) during the making of compost heaps were unnecessary. Instead, semi-solid cowdung was added and the surplus water sticking to plants diluted cowdung in the layer below and in course of draining away effected thorough mixing with the water hyacinth layer underneath. Another important point was the taking of over-ground heaps. It was difficult to have dry pits, particularly in the rainy season, due to high rainfall and subsoil water-table in Bengal and the compost charged pits were susceptible to holding outside water to delay decomposition and cause leaching of soluble nutrients. Heaps were comparatively free from these drawbacks and had additional advantages over pits in dispensing with the cost of digging and in facilitating draining out of surplus water and evaporation of excess moisture, which hastened decomposition.

"The heaps were left exposed to sun and air for 4 to 6 weeks, in which interval excess water was slowly lost with corresponding rise in temperature and growth of fungus; fermentation proceeded fairly rapidly and the heaps sank down to half the former level into a damp moist mass. If there was occasional rain it brought down temperature and slackened fermentation; fungus growth was scanty and sluggish. Although soft leaves and stalks were quickly fermented, the stems were a bit more resistant and after 4 to 6 weeks turned brown and partially decomposed but still retained hardness, particularly if dung was not added in the making of heaps. After the said interval the whole mass was given a complete turning, 2 or 3 sunken heaps

making a new one of parent size. If manure was required in 3 months, an extra turning could be given to the mass 4 weeks after the first. If manuring season was far ahead, after the first turning the heaps could be made dome-shaped and plastered well all over with cattle dung, alone or mixed with canal mud. Such a simple device, while allowing semi-aerobic fermentation to proceed slowly to complete ripening of the manure, offers protection to compost heaps from sun, rain and free aeration and helps in conservation of manurial ingredients, otherwise likely to undergo rapid loss. The fermentation was generally complete in 3 months (in dry season) to 5 months (in rainy season), when compost lumps could be broken down to finely divided brown powder resembling leaf mould. The average volume of per capita production of manure per day was 110 ft^3 [3.1 m^3] of fresh compost."

Basak tabulates the analyses of water hyacinth compost compared with town compost and farmyard manure.

Chemical composition of compost manures (dried)

	Water hyacinth compost	Town compost	Farmyard manure
	%	%	%
1. Nitrogen	2.05	1.0	0.50
2. Phosphoric acid (P_2O_5)	1.10	1.0	0.25
3. Potash (K_2O)	2.50	0.80	0.30
4. Lime (CaO)	3.91	3.0 to 5.0	0.2
5. C/N ratio	13	10	12 to 13

Bates, R.P. and J.F. Hentges, Aquatic weeds - eradicate or cultivate? Econ.Bot., 30(1): 1976 39-50

In a general review of the utilization of aquatic weeds the authors state: "The simplest and least costly conversion which can be accomplished is merely to compost the aquatic plants. Suitable compost has been produced, although plant nitrogen conversion to nitrate is not ideal. There is some indication that soil microflora can be adversely influenced by improper aquatic weed addition to soils. Thus the complex interactions between plant material, soil and microflora will require detailed study, if practical soil conditioning uses are to evolve."

Boyd, C.E., 7. Utilization of aquatic plants. In Aquatic vegetation and its use and 1974 control, edited by D.S. Mitchell. Paris, Unesco, pp.107-14

The author reports that Salvinia molesta has been used as a mulch on gardens in the vicinity of Lake Kariba. It is particularly useful if mixed with the dung from game animals such as elephant or buffalo, or when placed in a chicken run for some days so that it partially dries out and becomes mixed with the chicken droppings.

Chokder, A.H., Further investigations on control of aquatic vegetation in fisheries. 1968 Agric.Pak., 19(1):101-18

The author states that water hyacinth ash has a commercial value as a base for fertilizers, especially potash fertilizers. It contains 25-27% K as K_2O. Other plant nutrients in the ash are of negligible importance. The ash has more value for fertilizer than other preparations of water hyacinth.

*Day, F.W.F., Water hyacinth as a source of potash. Agric.Bull.Fed.Malay States, 6(7/8): 1918 309-14

The author describes the manurial value of water hyacinth especially in regard to its potash content, which is particularly high in the stalks. He describes methods of burning the plant and collecting and storing the ash. He adds: "Experience will show whether a little lime should be mixed with the ash as probably this would keep the phosphate in the residue."

*Finlow, R.S. and K. McLean, Water hyacinth and its value as a fertilizer. Calcutta, 1917 India, Govt. Printer, 16 p.

Experiments on the use of water hyacinth as a fertilizer for jute were carried out either after the hyacinth had been heaped and allowed to rot or after burning to ash.

"For tests on the jute crop about 30 tons of fresh hyacinth was collected in Dacca. Some of this was heaped and allowed to rot and the remainder dried and burnt. There was a considerable loss of liquid squeezed out from the rotted material which resulted in a loss of potash as shown by the following:

100 parts by weight of fresh hyacinth yielded: after rotting - 6.6 lb [3 kg] K_2O
after burning - 30.5 lb [14 kg] K_2O

There was thus a loss from rotting material of 70% available potash, and 60% of the nitrogen was also lost. It is thus recommended that hyacinth before stacking should be partly dried, or alternatively fresh hyacinth should be mixed with earth or dry plant material in the stack.

On a total of about 72 plots, of which 22 were checks, a variety of treatments were applied including rotted hyacinth, rotted Pistia, hyacinth ash and various fertilizers including potassium sulphate and potassium chloride. The results gave a clear indication of marked response of jute to potash (about 25% increase in yield) a result which was also obtained when hyacinth ash containing an equivalent amount of potash (94 lb K_2O/acre) [105 kg/ha] was applied. Good results were also obtained from rotted Pistia.

In Bengal water hyacinth contains considerable stores of plant food of which potash is the chief constituent. If rotted, the residue contains about the same amounts, or more, of nitrogen and phosphoric acid as ordinary farmyard manure; and it is several times as rich in potash: it has about the same water content (60%). The dried hyacinth material weighs about one-twentieth of the fresh and thus is in a more convenient form to transport. It contains from 1.5 to 2% of nitrogen and about 8% of potash.

After burning, the ash residues of clean water hyacinth (unmixed with earth) have been found to contain as much as 35% of potash (K_2O), and an average figure for the Dacca district would seem to be over 25%. The ash is therefore several times richer in potash than ordinary wood ashes.

The results of the field tests showed conclusively that water hyacinth is a valuable manure either in the rotted state or as ash on laterite soils of the old alluvium in Bengal. Some of the various silts of the new alluvial tracts exhibit potash deficiency and there is little doubt that hyacinth, either rotted or as ash, will prove equally valuable for them. On the high, light, well drained soils the rotted material may be preferable but on heavy low-lying lands the ash would probably be more successful."

*Gratch, H.I., 1968 Water hyacinth - a menace that could be turned to a blessing. In Handbook of utilization of aquatic plants, edited by E.C.S. Little, Rome, FAO, Plant Protection and Production Division, PL:CP/20:16

The author estimates that about 200 000 ha of water bodies throughout India are infested with water hyacinth and carry about 250 t/ha. As about 10 t of compost can be made from 100 t of water hyacinth there is a potential of about 5 million t of compost. He cites the analysis given by Basak (1948). He contends that the cost of making the compost is mainly derived from the labour needed to harvest it and make the heaps. The compost should be used at the rate of 5-7.5 t/ha. Preferably it should be fortified by mixing in superphosphate at the rate of 1 part of super to 20 parts of compost. The clearing of the hyacinth and using it for compost would not only lead to increased crop production but also would increase fish yields in the tanks from which the weed was cleared.

Hortenstine, C.C. and J.V. Parra, 1973 Water hyacinths as a soil amendment and source of plant nutrients. Abstr.Meet.Weed Sci.Soc.Am., 1973

Control measures for water hyacinth which use chemicals allow the plants to become part of the detritus and thus create a permanent sink for plant nutrients. Complete removal of the hyacinth with subsequent disposal in soil would alleviate this nuisance in affected waters, lower the nutrient content of these waters and benefit the soil, especially sandy soils. Normal soil has an average C/N ratio between 9 and 12 which is maintained at almost a fixed value. Therefore when organic matter with a C/N ratio greater than 12 is added to soil, micro-organisms must draw upon the soil N in order to assimilate the added C; water hyacinths generally have a C/N ratio between 25 and 30. (From Weed Abstracts)

*India, Council of Scientific and Industrial Research, 1952 The wealth of India. Vol. 3. Raw materials. New Delhi, CSIR, pp.130-4

In a review of utilization of water hyacinth it is stated that the laterite soils of the old alluvium of Bengal and some types of silt comprising the new alluvial tracts are deficient in K, P and lime. So water hyacinth, either rotted or ashed, is a valuable manure for them. For light, well-drained soils the rotted material may be preferred; for heavy low-lying lands the ash may be used with advantage.

Water hyacinth, mixed with earth, cow dung and wood ashes in the Chinese compost fashion gives a compost in about two months. It is necessary to use wilted rather than fresh plants in the compost heap as due to the high water content the juice from the fresh plants is expelled and lost during stacking.

Hyacinth compost contains on an average (dry matter basis):

N - 2.05%; P (as P_2O_5) - 1.1%; K (as K_2O) - 2.5%; Ca (as CaO) - 3.9%;

and the C/N ratio is 13. Bulk for bulk hyacinth compost is twice as rich as town compost and four times as rich as farmyard manure in K. It is eminently suitable for jute and rice fields, for vegetable gardening and fruit growing. It can be produced at low cost and large-scale trials have demonstrated that water hyacinth control through composting is both practical and profitable.

Kamal, I.A. and E.C.S. Little, The potential utilization of water hyacinth for horticulture
1970 in the Sudan. PANS, 16(3):488-96

The World Food Programme initiated a project to encourage the removal of water hyacinth from the Nile river by hand (see also Chapter IV) and then to put it to use for horticulture as mulch and/or fertilizer. Experiments were carried out to determine the rate of drying of fresh hyacinth as a means of reducing the cost and difficulty of transportation, and to improve the condition of the material for composting. Trials were also carried out, at different sites, on the effectiveness of layers of hyacinth of different thicknesses as a means of killing or suppressing infestations of two of the most difficult and persistent weeds, Cyperus rotundus and Cynodon dactylon.

The following tables summarize the results of the weed control trials:

Control of weeds (mostly Cynodon dactylon and Cyperus rotundus) by different thicknesses of water hyacinth mulch. Weed cover at time of treatment was 100%

Table 1 Trial 1

No. of layers of hyacinth applied 24 Jan.	Effect on aerial parts of weeds		
	13 February (after 21 days)	23 April (after 59 days)	25 October (after 275 days)
No cover	No change	No change	No change
2 layers	Etiolation	60% dead	100% dead
3 layers	Etiolation	80% dead	100% dead
4 layers	Etiolation	80% dead	100% dead
6 layers	Etiolation	80% dead	100% dead

Table 2 Trials 2 and 3

No. of layers of hyacinth applied 25 Jan.	Effect on aerial parts of weeds			
	25 April (after 90 days)		6 September (after 225 days)	
	Trial 2	Trial 3	Trial 2	Trial 3
No cover	No change	No change	No change	No change
1 layer	40-50% kill	60% kill	20% kill	20-50% kill
2 layers	60-90% kill	50-100% kill	50-60% kill	90-100% kill
3 layers	60-100% kill	60-100% kill	70-100% kill	95-100% kill

The following table summarizes the results of composting trials. The pits were made 2 m x 1 m and 0.5-1.0 m deep. When using cow dung or soil these were added in layers 2-3 cm deep at every 20-30 cm height of the pile.

Results from composting water hyacinth by different methods

Method (Pits made 24 Jan)	Results observed	
	24 April	6 September (after rainy season)
1. Fresh hyacinth alone	Very little decomposition	Patchy decomposition
2. Fresh hyacinth with cow dung layers	Decomposed to depth of 40 cm	Decomposed completely
3. Dried hyacinth with cow dung layers	Little decomposition	Decomposed to a depth of 95 cm

The authors make the following conclusions and recommendations:

"Hyacinth can be fully sun-dried before using as mulch. Using hyacinth for mulch could consume large quantities of the weed, especially if employed on the more important crops such as cotton or sorghum. After 8–12 months the mulch could be worked into the soil.

Compost from hyacinth. Good compost can be made from hyacinth but further research is needed to determine the most efficient method. Neither fresh material nor completely dry material appears suitable, though dry material might be satisfactory if the right amount of water were added to the clamp. It is estimated that hyacinth dried to about half its fresh weight may be the most suitable. Addition of layers of manure is clearly beneficial but layers of soil may be an adequate alternative. Digging of compost pits in the conventional way near the river banks may lead to damage from a rising water table when the river is at a high level. Compost clamps built on the soil surface are thus preferable.

The amount of compost required by soils near the Nile and its tributaries may be 100–125 tonnes/ha for which some 500–625 tonnes of fresh material would be needed.

The effect on the viability of hyacinth seeds after composting should be determined to assess the safety of moving compost any substantial distance from the area of collection.

Burning hyacinth: Hyacinth completely or partially burnt after drying would produce a product of fertilizer value though lacking in some or all of its nitrogen content."

Mara, M.J., Estimated values for selected water hyacinth by-products. Econ.Bot., 30(4): 1976 383-7

The author reviews the value of various by-products which can be obtained from water hyacinth. The calculations are based on demand and supply in the U.S.A. and on local currency. Though the prices are, of course, no longer applicable a summarized version is given below because relative costs may remain applicable.

(a) Plotting compost. In 1973 the production costs for a finished compost made with half water hyacinth and half peat was US$1.31/bushel (36.4 litres). It was sold at US$1.75/bushel. Thus the firm manufacturing the product could pay at most US$0.44 for the water hyacinth needed per bushel of dry compost. This amount converts to US$98.20/dry ton or, at most, US$6.42/wet ton (this calculation was based on 21.7 bushels/cubic yard (0.76 m^3) and 5.14 cubic yards/ton). The wet to dry ratio of water hyacinth was found to be 15.3 and was constant throughout the growing season (but with a standard deviation of 2.1). This worked out at a water content of the hyacinth of 93.4%. Mara considered that the market at this calculated price might not be large.

(b) Soil amendment. Mara states that water hyacinths may have some value as compost when used alone. If hyacinths are used as a soil amendment their value must cover the costs of transporting, spreading and working them into the soil. The fertilizer value (1974) of 1 t of water hyacinth was approximately US$0.30 based on the assumption that 300 t of hyacinth is equivalent to 1 t of 8–8–8 fertilizer. Additional to this value the hyacinths would be worth something for the improvement they would give to the soil. Transportation cost was estimated at US$0.27/ton/mile (1.6 km). This cost suggests that hyacinths would not be in demand as compost by farmers located more than one mile from the source of supply. If all costs were considered it is doubtful whether any hyacinths would be wanted for soil amendment at even this relatively short distance.

Mohamed, B.F. and F.F. Bebawi, Burning as a supporting treatment in controlling water
1973 hyacinth in the Sudan. 1. Routine burning. Hyacinth Control J., 11:31-4

_____, Burning as a supporting management in the control of water hyacinth in the
1973a Sudan. 2. Back burning. Hyacinth Control J., 11:34-7

The authors describe methods of efficient burning of dried mounds and carpets of water hyacinth, either harvested into piles or deposited onto the banks by flooding. The papers are concerned primarily with the destruction of the plant accumulations and particularly of viable seeds that they contained. However the papers are cited because they could be useful to those interested in retrieving the ash from such fires for fertilizer purposes. A warning is given that seeds may not always be destroyed if the temperature of the fire does not reach an adequate level due to the presence of insufficiently dry material in the piles.

Moore, A.W., Azolla: biology and agronomic significance. Bot.Rev., 35(1):17-34
1969

Reviewing the literature on Azolla spp. Moore describes the nitrogen-fixing capacity of this water fern which is attributed to its symbiotic relationship with a blue-green alga, Anabaena azollae. (The yields and amount of N fixed are given in Chapter III.) Thus Azolla has clearly a potential value as a fertilizer. It has been used extensively in Vietnam as a green manure for rice which is harvested in May and June. For 20 years the Ministry of Agriculture in North Vietnam organized over 1 000 depots for multiplying Azolla for the farmers. In 1957 it was claimed that 90 000 ha had been fertilized with Azolla with consequent increase in rice production. The best periods for vegetative growth of Azolla are during August-September and January-February. At these times the plants double in number every 5-7 days, when the temperature is optimum at 16-17°C. Just before, or after, rice transplanting Azolla is scattered in the fields, at a rate of about 10 m^2/ha, and it grows along with the rice during January and February. Towards the end of March the temperature rises to a mean of 22-24°C when the Azolla dries off and forms a sediment on the bottom. The rice is at the boot stage at this time and starts to become greener. Growth and tillering then accelerate. By the time of harvest (May-June) little or no Azolla remains. Trials have measured a 14% increase in rice yield from this treatment.

Another trial with rice in North Vietnam gave a yield of 1 760 kg/ha from an untreated control plot; 2 500 kg/ha from a plot to which 5 000 kg/ha of manure had been added, and 3 500 kg/ha from a plot with 2 500 kg of manure plus Azolla.

Moore comments: "Azolla appears to be capable of fixing N in the field in a similar way to a leguminous crop. So it can be considered to have a potential value in paddy rice cultivation provided the rice crop is not preceded by a legume, nor fertilized directly with N fertilizer. However since this practice is used traditionally in only a limited area of S.E. Asia it suggests that problems of management are involved. In Japan Azolla in the rice crop is considered to be a weed. Under these circumstances it may have a role as a green manure in unused paddy fields. Azolla must be killed before the N it contains becomes available. So it may be that it is the convenient rise in temperature in North Vietnam a month before the May-June harvest which kills the Azolla and makes it useful as a fertilizer. In most tropical rice-growing areas temperatures decline during the growing season."

Parra, J.V., 1975 Use of water hyacinth as a soil amendment and source of plant nutrients. Diss.Abstr.Int.(B), 36(2):1016-17

Water hyacinth was used as a soil amendment and fertilizer in greenhouse and field experiments in Florida, U.S.A. Optimum levels of water hyacinth for maximum yield were above 4 000 ppm in Arredondo fine sand. For Lakeland and Leon fine sands optimum levels varied between 6 000 and 8 000 ppm. Nutrient uptake was enhanced by hyacinth applications in all soils. Residual effects of hyacinth resulted in higher C, N, K, Ca, Mg and Mn content of all soils. The Zn content of Lakeland and Leon soils was increased and exchangeable Al reduced.

In the field, water hyacinth rates of 0, 15 000 and 30 000 kg/ha (dry matter) were incorporated in Wachula fine sand. Pearl millet, Pennisetum americanum, was grown as indicator crop. Basal fertilizer rates were N-P-K at 0-0-0, 30-13-25, and 60-26-50 kg/ha. After the first harvest 80 kg/ha was applied to all treatments. Two harvests were collected and analysed for nutrient uptake. Pearl millet yields were higher on all water hyacinth treatments than on fertilizer treatments. In the second harvest basal fertilizer depressed yields and nutrient uptake on plots amended with water hyacinths. The optimum level for maximum yield was 27 000 kg/ha of water hyacinths. The content of C, N, P, K, Ca, Mg, Zn, Mn and Cl, and effective cation exchange capacity of Wachula fine sand were increased by addition of water hyacinth. Soil pH was not affected as the soil was limed prior to water hyacinth incorporation.

Parra, J.V. and C.C. Hortenstine, 1974 Plant nutritional content of some Florida water hyacinths and response by pearl millet to incorporation of water hyacinths in three soil types. Hyacinth Control J., 12:85-90

Pot experiments were carried out in Florida, U.S.A., to measure the fertilizing effect of water hyacinths in three different soils. The plants were dried and ground and added at 0, 2 231, 4 462 and 8 924 ppm to the soils with and without added fertilizer. Pearl millet, Pennisetum typhoides, was used as the test crop.

One soil, Arrendondo, pH 6.5, had nearly ideal characteristics for plant growth. The addition of water hyacinth did not increase millet yield in the first crop, but when included in addition to fertilizer there was a positive response over and above the response to fertilizer alone. Fertilizer in terms of N-P-K was added at 0,0,0; 45, 25, 50; and 90, 50, 100 ppm. For the second millet crop in the same pots yields were much less than for the first crop and the residual effect of fertilizer alone was not significant. However there was a residual effect from water hyacinth with or without added fertilizer. Water hyacinth appeared to enhance nutrient uptake through a possible improvement of the root environment in addition to maintaining a source of plant nutrients.

On a less fertile sandy soil, Lakeland, pH 5.0, there was a greater response by the crop both to fertilizer and water hyacinth applications with greater residual effects. The best response was to the lowest rate of water hyacinth application.

The least fertile soil, Leon sand, pH 4.8, gave the biggest responses, with water hyacinth alone giving as good or better yields than fertilizers alone. Second crops were also better, reaching 74% of the first crop yields. In addition to increasing yield, water hyacinth applications increased N-P-K uptake by both crops of millet.

The authors comment that the relatively high 7.5 pH of the water hyacinth would certainly be a beneficial characteristic where large quantities of water hyacinths are disposed of on sandy acidic soils. The high base content would also probably be effective in reducing aluminium toxicity in unlimed soils.

Parra, J.V. and C.C. Hortenstine, 1976 Response by pearl millet to soil incorporation of water hyacinths. J.Aquat.Plant Manage., 14:75-9

The material in this paper describes in more detail the results reported in Parra (1975).

In the introduction, in which literature is briefly reviewed, the authors state that organic sources of nutrients, particularly organic N compounds and organic chelates of heavy metals, may have unique value in plant nutrition under some circumstances because of their solubility, or because of their steady release of available forms of nutrient elements. The benefits to be derived from the incorporation of organic matter into the soil are well known, and become of paramount importance in sandy soils which are low in organic matter and deficient in most plant nutrients. Water hyacinths contain fairly high concentrations of plant nutrients as compared to other species and would be very desirable green manures.

Reimer, D.N. and S.J. Toth, 1969 A survey of the chemical composition of Potamogeton and Myriophyllum in New Jersey. Weed Sci., 17(2):219-23

_____, 1970 Chemical composition of five species of Nymphaeaceae. Weed Sci., 18(1): 4-6

The authors carried out analyses of Potamogeton spp, Myriophyllum spp and other genera in the family Nymphaeaceae (see Chapter III).

In the 1969 paper they refer to the wide variation in composition of aquatic plants and explain their interest in respect of the utilization of such plants for composts. They state: "It is recognized that when the total N content of plant tissue is between 1.5-2.0%, or higher, no extra N need be added to ensure proper decomposition of residues. The analytical data indicate that species of Myriophyllum and Potamogeton contain sufficient total N for decomposition. Partial drying of the cut plants before composting however will be necessary to reduce anaerobic decomposition to a minimum. The final composts prepared from the aquatic plants probably will contain fairly high amounts of minor elements, especially Fe, Mn, and Zn which may be beneficial. It is believed that the composts will need the addition of extra P and K."

In the 1970 paper they conclude: "In the previous paper it was pointed out that plants with 1.5-2.0% N or higher do not require addition of extra N for composting. Of the tissues reported in this paper only the petioles of Nuphar advena, Nymphaea odorata, and Nymphaea tuberosa fall below these values. The leaf blades of these species and the top growth of Brasenia schreberi and Cabomba caroliniana contain sufficient N for decomposition."

"It was also pointed out in the previous paper that partial drying of the cut plants probably would be necessary to reduce anaerobic decomposition to a minimum. Except for Cabomba the Nymphaeaceae reported on here are coarse in structure and excess water should drain off quite readily and afford little problem."

Riemer, D.N. and S.J. Toth, Nitrification of aquatic weed tissues in soil. Hyacinth
1971 Control J., 9(1):34-6

This paper describes laboratory tests of the potential usefulness of 16 aquatic weeds for disposal, after harvesting, by composting. The objective was to determine the rate and degree of nitrification of dried, ground aquatic weed tissues when added to soil under aerobic conditions. The weeds were compared with untreated soil, alfalfa (lucerne) and ammonium sulphate, which is an easily nitrified source of nitrogen. Over a period of eight weeks the amount of nitrogen in the plant tissue which was nitrified in the soil was measured. Considerable variations were observed. Myriophyllum heterophyllum and Elodea canadensis nitrified at about the same rate as alfalfa (20-25%). Cabomba caroliniana did not nitrify at all. In another test Nuphar advena nitrified to 58%, which was much higher than alfalfa, but the leaf petioles did not nitrify. Phragmites communis was much lower, as was Peltandra virginica (12-15%).

In a further test with P. communis it was found that young plants (0.5 m tall) with a high N content gave moderate nitrification but that older plants (2-3 m tall) not only did not nitrify but they inhibited nitrification of the nitrogen already in the test soil.

In a final test Lemna minor gave a higher nitrification rate than alfalfa (40-50%). Utricularia sp. was equivalent to alfalfa. Potamogeton pulcher, P. cordata and Sparganium sp. all gave negative nitrification results.

The following conclusions were drawn:

(a) Aquatic plants show great variation in the conversion of plant nitrogen to nitrates by soil micro-organisms.

(b) Some tissues not only show poor nitrification but inhibit nitrification. This may be due to chemical inhibitors, or to high carbon-nitrogen ratios. Alternatively high microbial populations utilize nitrates so fast that low nitrate values are obtained.

(c) The older plants of one emergent species (Phragmites) appear to inhibit nitrification. No data are available for floating or submerged species.

(d) Some aquatic weeds may be composted for agricultural use without the addition of extra nitrogen, but not all.

*Schultz, H., Brazil's big-lipped Indians. Natl. Geogr.Mag., 121(1):118-33
1962

A traditional method used by native Indians in Brazil is to burn water hyacinth as a source of potash in place of common salt.

*Singh, S.B., Preliminary experiments on the relative manurial values of some aquatic
1963 weeds as composts. Proc.IPFC, 10(2):141-5

Five aquatic plants were composted at the Central Inland Fisheries Research Substation, Cuttack, India, and their analyses compared with that of cow dung and garden soil as shown in the following table:

Compost	pH	Organic C %	Available N mg/100 g	Available P mg/100 g
Pistia sp.	7.5	1.3	38.1	10.1
Hydrilla sp.	8.2	1.9	59.9	6.6
Najas sp.	7.6	1.2	47.6	13.6
Ottelia sp.	7.5	1.4	48.7	10.1
Eichhornia sp.	7.3	1.1	35.8	11.8
Dry cow dung	-	17.2	84.0	10.1
Garden soil	7.6	0.8	22.4	6.6

In preparing the composts in pits it was found best to air-dry the weeds for a day or two first. For composting the plants were mixed with equal quantities of soil and dry cow dung in early experiments. In later experiments the cow dung was omitted in order to improve comparisons between the different plants. Fibrous plants like Hydrilla and Najas and the roots of Eichhornia and Pistia took a comparatively long time to decompose. Hydrilla compost took 1½ months to get ready; the others took one month.

Crops of tomatoes and lady's finger were grown on plots to which these composts had been added at the rate of 28 tonnes/ha, in four weekly applications of 7 tonnes/ha.

The conclusions from the trials were that the yield of tomatoes and lady's finger were increased by all the water plant composts except Eichhornia, which consistently gave yields lower than crops grown in the garden soil only. The author, however, feels that his results show that water plant composts are useful for manuring fish ponds or as agricultural fertilizer. He suggests that composts appropriate to the nutrient needs of various crops could be prepared by a judicious mixture of water plants having the necessary analysis of plant nutrients.

Subagyo, T. and N.V. Vuong, Biological studies of Salvinia molesta. BIOTROP Newsl., (12) 1975

Dead masses of Salvinia molesta stimulated the growth of rice seedlings in Indonesia. No significant difference was found between the use of fresh or dry material as a mulch on the growth of rice seedlings. The mulch increased the dry weight by 40% and the number of tillers by 30% of lowland rice seedlings six weeks after planting. (From Weed Abstracts)

Sudan, National Council for Research, Agricultural Research Council, Aquatic weed management: some prospects for the Sudan and the Nile Basin. Report of a Workshop held 24-29 November 1975. Khartoum, Sudan, National Council for Research, 157 p.

This book reports on the work of Abdalla and Hafeez, 1969 (see also p.114). Reference is also made to the usefulness of water hyacinth compost, claimed to be equivalent to farm yard manure in respect of N and P content, and having a much higher content of K.

Thompson, T.W. and H. Hartwig, Control of watermilfoil in large Wisconsin lakes. 1973 Hyacinth Control J., 11:20-3

The authors report the successful disposal of Myriophyllum spicatum and M. heterophyllum as a soil conditioner. The plants were prepared by chopping and dewatering.

*Watson, E.F., The utilization of water hyacinth. Indian Farming, 8(1):29-30 1947

After pointing out the usefulness of compost the author describes how it can be made from water hyacinth.

"Water hyacinth should not be composted in the fresh green state, otherwise it will settle down into the sort of soggy mass that we see when it is piled on the edges of tanks. Nor should it become bone-dry as that would necessitate getting it all moist again. If when removed it is spread out in a thin layer to wilt in the sun for a week or two, it will be just about right. Even then to avoid its compacting into a solid mass through which air cannot penetrate, it is always best to mix some other material such as rough dry grass, wilted jungle or fallen leaves with it.

"The simplest way of making compost in the first instance, and until one uderstands the process sufficiently well to tackle it on a large scale, is to use a circular framework made of bamboo. A convenient size is 5 ft diameter [1.5 m] at base, 4 ft [1.2 m] high and 4 ft 6 in. [1.37 m] diameter at top. This taper is to enable it to be lifted off without sticking. This should be put up on a plot of well-dug earth and roughly mud-plastered inside except for the bottom 6 inches [15 cm]; this is to prevent strong winds blowing through it.

"The well-wilted water hyacinth, together with any other vegetable refuse available, is spread evenly in a layer about 9 in. [22 cm] thick. Over this a layer of any fresh manure is put an inch [2.5 cm] or more thick; urine-soaked bedding is best of all. Then a layer of wood ashes, or finely powdered earth, is evenly scattered over the whole; that obtained from the scraping of cattle stances or the cleaning of drains is the best but it must be dry and finely powdered to spread evenly.

"Turn over the whole two or three times to get it thoroughly mixed. Every leaf should have a little manure and a little earth adhering to it. Then stick a 5 ft [1.5 m] bamboo lightly into the ground in the middle of the bamboo framework and toss all the material in round it, piling up as much on the top as can be managed to stay. Leave for four days (by which time it should have settled to half the height) and remove the central bamboo stake, the bottom of which should be too hot to touch if the material has been mixed properly.

"The aeration hole thus left will start smoking at once. Failure to heat up generally means that the material has been mixed too wet which helps making silage instead of compost. If this is the case lift off the bamboo framework, spread all the material out for an hour or two to dry a little and then refill as before. The heap should continue steaming for a fortnight and then slowly cool down. If it cools too quickly, it probably indicates stinted wood ashes and earth.

"After 20 days the framework can be lifted off and set up alongside while the still hot material (which should now be completely covered with grey fungus mycelium) is mixed and reloaded in it. Any over-dry parts should be put in the middle this time and over-damp parts round the edge. The bamboo pole should be put in as before and removed after four days. In another 10 days the framework can be removed altogether and used again for starting a fresh compost heap.

"The first made heap should be left two months to ripen, after which (three months from the start) it will have become a brown friable compost ready for immediate use. Nothing needs to be done to it during this time beyond an occasional light watering of the outside, should the weather be very dry. If not wanted at once it should be stored under cover or the tops of heaps made conical and covered with a little earth to ward off heavy rain."

* Anon., 1966 Notes and news. Mulching with water hyacinth (Eichhornia crassipes). Two Bud, Newsl.Tea Res.Assoc.Tocklai Exp.Stn., 13:31

The author describes the mulching of tea bushes with water hyacinth in India.

"There is usually an abundant supply of water hyacinth in most estates. It is extremely good for use as a mulch in young tea areas during the dry period for conservation of soil moisture. In the droughty regions, particularly in the hot southern slopes of the teelas in Cachar, this is of particular benefit. The plants are best used wet, as this adds some moisture as well to the soil. This mulch slows down the rate of evaporation from the soil. It also keeps the soil surface permeable and reduces the run-off of the rain and consequently reduces the amount of soil the water can carry away, and increases the proportion of the rain or irrigation water that percolates into the soil. Mulching can, therefore, be used with advantage in irrigated areas as well.

"The water hyacinth plants are of great manurial value as well and the dried ones of the local varieties contain about 70% organic matter, 1.5% nitrogen, 0.6% phosphorus and about 5.5% potash. When the dry period is over, all the undecomposed matter should be removed from near the collars of the bushes and heaped in between the rows of tea till completely decomposed. The soils of all poor tea areas are normally very deficient in organic matter and mulching with water hyacinth will not only add the minerals deficient in the soil but will also improve the physical texture."

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Knapsack sprayer in dug-out canoe used for weed control on Rawa Pening lake, Central Java, Indonesia

Workers carrying fresh hyacinth to mulch plots (left) at Malakal on the Nile river, Sudan. Plots for drying experiment on right

A completed compost clamp covered with a layer of earth. In the background are plots with different thicknesses of fresh water hyacinth applied as a mulch

X. WATER PURIFICATION

This is probably the most important chapter in this handbook. The subject was only briefly mentioned in the first edition. Several papers did refer to the capacity of water plants to extract plant nutrients from the water in which they grew. But the interest in this rather obvious fact was related to the ability which this property conferred to farmers in South-East Asia to establish a nutrient cycle. This double cycle, plants-pigs-humans-fish-humans-plants, enabled a limited set of nutrients to be continually reutilized in ponds in a system powered by the sun. Other papers, which described the fertilizing potential of water plants, recognized that the nutrient content of water plants had been salvaged from water and might otherwise have been lost to the sea.

The reason which has prompted the spate of papers within the last ten years on the nutrient extraction possibilities of aquatic plants is the increasing awareness of the problems of water pollution - both fresh and salt water - as a consequence of population growth and industrial development, and the disposal of human, animal and industrial wastes into inland waters and into the sea.

In the past industrial wastes scarcely existed and human and animal wastes were carefully returned to the land to conserve the fertility which it was recognized that they contained. Now it is often cheaper to buy fresh supplies of fertilizer in concentrated, easily applied forms and flush away wastes into sewers or streams. Many examples of the devastating consequences of this waste on formerly clean and useful rivers and lakes have aroused public and scientific awareness of the need not only to arrest this practice but to try and reverse it by extracting the pollutants. The remarkable ability of aquatic plants, particularly the water hyacinth, to extract compounds and elements from water efficiently has become well recognized.

It is particularly interesting that among the scientists who have devoted their energies to this subject are those of the U.S.A. National Aeronautics and Space Administration. The National Space Technology Laboratories have recently published a series of papers on the usefulness of water hyacinth (Eichhornia crassipes) and also alligator weed (Alternanthera philoxeroides) in removing pollutants from sewage and industrial waste. The U.S. National Academy of Sciences have included in their book "Making aquatic weeds useful: some perspectives for developing countries" (1976), a chapter on "Wastewater treatment using aquatic weeds", which gives a useful illustrated summary of recent work together with a valuable list of references. As the book is recent and readily available there is no need to cite the data reviewed in it on the uses of water hyacinth, duckweeds (Lemna spp.), submerged and emergent weeds, all of which are shown to have a potential and actual use for purifying water. One interesting item mentioned is research in progress to see if aquatic plants can be used to extract silver, gold and other precious metals from ore-refining waste waters.

The interest of the U.S.A. in the subject of water purification by aquatic plants is emphasized by the fact that of the 48 papers cited in this chapter only seven are from outside the U.S.A.

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Boyd, C.E., 1970c Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ.Bot., 24:95-103

This paper is one of the earliest to go into the question of reducing the pollution of lakes by the harvesting of aquatic plants which have withdrawn nutrients from the water. The author points out that all aquatic plants can serve this purpose but small plants, like phytoplankton, or submerged plants are more difficult and expensive to harvest than the floating and emergent vascular plants. Four species are considered suitable: Eichhornia crassipes (water hyacinth), Alternanthera philoxeroides, Justicia americana and Typha latifolia. (For mineral content and productivity see Chapter III.) Boyd points out that plants grown in nutrient-rich effluent would probably contain 1.5 to 2.0 times the mineral analyses figures given.

Boyd states that water hyacinth would be ideally suited for nutrient removal systems. As it floats on the surface and is not rooted, harvesting is facilitated. By continuous harvesting the population could be kept in a rapidly expanding phase during which uptake rates of nutrients are at their highest. Waters beneath dense stands are anaerobic so additional N would be lost by denitrification. There would be considerable microbial activity beneath the hyacinths and nutrients would be absorbed by these organisms. In addition considerable organic matter would reach the water by the loss of root fragments and probably have a fairly high biological oxygen demand (BOD) and it might prove necessary to use conventional sewage holding ponds to reduce the BOD prior to final release.

Alternanthera philoxeroides could probably be best harvested by draining the pond and then using modified forage harvesting equipment. Typha latifolia as an emergent species could be grown in ponds about 1 m deep so that the water remains anaerobic, allowing bottom soils to remove P from solution. But it would be better, if space permitted, to grow the plants in water 15-20 cm deep to maximize soil absorption of P. At a stage when P equilibrium had been reached then the ponds could be dried and used for conventional crops until the P levels are reduced.

In nutrient-rich waters phytoplankton frequently produces dense growth and prevents the development of rooted species by light limitation. This could be avoided by starting the plants in shallow water and increasing the water depth as the plants grow. Ponds could be started at different dates so that harvesting could be staggered and thus a constant supply of plants for feedstuffs would be provided. Water hyacinth would not need these arrangements, but as it cannot overwinter in temperate olimates it would have to be introduced in early spring. There would be some danger in introducing these plants into new areas, but it would be minimal for J. americana and T. latifolia.

Large quantities of nutrients are taken from the water, as shown in the following table:

Quantities of elements that could be removed by continual culture of some aquatic plants (kg/ha/year)

Element	E. crassipes	J. americana	A. philoxeroides	T. latifolia
N	1 980	2 290	1 780	2 630
P	320	140	200	400
S	250	200	180	250
Ca	750	1 020	320	1 710
Mg	790	470	320	310
K	3 190	3 720	3 220	4 570
Na	260	190	230	730
Fe	19	120	45	23
Mn	300	13	27	79
Zn	4	30	6	6
Cu	1	3	1	7

At the rates shown 1 ha of pond would be sufficient to extract the N contribution in domestic wastes of 500 people, and the P from 225. The yield in protein from J. americana is calculated as being able to supply human requirements for one year based on a generous estimate of 70 g being needed per person per day.

Nutrient removal by plants would be most effective when the nutrient is concentrated. This is typical of the effluents from feed lots of cattle. If plants were grown on the ponds holding these effluents they could be fed to the cattle. This would be ideal because handling and transport of the plants would be kept to a minimum. Nutrient removal and plant utilization could also be handled by the same organization.

The author points out difficulties from mosquitoes and other insects breeding in the ponds, and the care needed to prevent disease transmission from the effluent to the plants.

Boyd, C.E., 1974. Utilization of aquatic plants. In Aquatic vegetation and its use and control, edited by D.S. Mitchell. Paris, Unesco, pp.107-14

The author reviews papers on the potential of aquatic plants, especially water hyacinth, for removal of nutrients from polluted water. He cites an example involving purification of water for fish culture. Farming of channel catfish (Ictalurus punctatus) involves addition to the water of large quantities of fish feed. Waste feed and the excretions of the fish lead to the development of dense blooms of phytoplankton. When the plankton die their decaying residues can result in oxygen depletion and fish kill. Water hyacinth, confined in barriers so that it only covers 10% of the pond, and regularly harvested, can remove sufficient nutrients to avoid excessive phytoplankton growth.

In shallow, polluted lakes the dominant vegetation is likely to be submerged plants. If these are regularly removed the levels of nutrients in the lake can be reduced to an acceptable level.

Boyd, C.E., 1976. Accumulation of dry matter nitrogen and phosphorus by cultivated water hyacinths. Econ.Bot., 30(1):51-6

Reviewing the literature Boyd cites three estimates of the amount of nitrogen and phosphorus that water hyacinth could be expected to extract from nutrient-rich waters under good growing conditions: (t/ha/year)

Nitrogen	Phosphorus	Reference
6.0	0.6	Steward (1970)
1.98	0.32	Boyd (1970c)
2.5 +	0.7 +	Rogers and Davis (1972)

The paper discusses experiments to determine the N and P uptake by water hyacinth from earthen ponds enriched with N and P by application of artificial fertilizer. The plants were contained within enclosures anchored to the middle of the ponds. As the plants grew to fill the enclosures half of the plants were removed periodically for weighing and analysis. The pond water was also analysed and the phytoplankton content determined. Fertilizer was broadcast over the ponds at two-weekly intervals to give N and P concentrations (N, 0.05 to 0.18 ppm; P, 0.01-0.08 ppm) equivalent to concentrations reported from eutrophic lakes. The chlorophyll content ranged from 19-65 µg/l indicating dense phytoplankton blooms (May-September).

Water hyacinth growth rates averaged (dry weight) 190 kg/ha/day. The author compares this with growth rates cited in the literature:

540 kg/ha/day - Yount and Crossman (1970). This was a maximum, most yields being between 150-200 kg/ha/day. A lower rate was: 146 kg/ha/day (Penfound and Earle (1948)).

Average rates of N and P removal over the entire period were 3.4 and 0.43 kg/ha/day, respectively. This is equivalent to an extraction, over 12 months of growth, of N, 1.20 t/ha/year; P, 0.16 t/ha/year. The hyacinths generally absorbed N 5-10 times as rapidly as P. The content of N in the plants decreased from June-September, while P content was similar at the end of June and September but lower at other dates.

The overall results for growth based on a 12-month period were between 39-142 t/ha dry matter which included: N, 0.8-1.8 t/ha; P, 0.1-0.3 t/ha.

The author concludes that these results, though lower than others cited in the literature above, are similar to those reported in his earlier paper (Boyd 1970c). The data confirm the capability of water hyacinth to remove large amounts of N and P from water.

Brink, D.N., 1969 Aquatic weeds. Proc.Swed.Weed Conf., 10:1-2

A river, into which sewage was being discharged, had a population of Sparganium ramosum, S. simplex and Butomus umbellatus. The amount of N and P discharged into the river was measured, as was the amount of these nutrients taken up by the plants to a distance of 8.4 km downstream from the sewage entry. It was found that about 4% of the N and 13% of P were assimilated by the vegetation. Most of this was later released to the water again when the plants died. Most of the sewage nutrients were deposited in the stream bottom by physical, chemical and microbial action. The author advocates mowing the vegetation as the best means of controlling it, and recommends that this be done in the first half of August, because at this time the plants contain maximum amounts of N and P.

Bryant, C.B., 1970 You need weeds. Proc.Annu.Meet.South.Weed Sci.Soc., 23:301-5

The author describes methods of harvesting aquatic weeds (see Chapter IV) and emphasizes the usefulness of aquatic plants in purifying water. He comments that water plants are one of the most efficient ways of extracting nutrients from water. By releaing oxygen they also contribute to water clarity. If large aquatic plants are eradicated their place is taken by algal blooms. This can be observed after weeds are killed by herbicides, when the decayed plants release the nutrients they contain back into the water. This may convert a clear lake into water with dense algal growth.

Denike, T.J. and R.W. Geiger, 1974 The utilization of Chara in water management. Hyacinth Control J., 12:18-20

The authors consider that the alga Chara spp (see Chapter VIII) is an excellent nutrient absorber. Management of eutrophic lakes has been arranged to suppress undesirable aquatic weeds while encouraging the growth of Chara. Under this system water clarity has been improved, in one case from 1 m to about 3 m, and in another from 0.3 m to 2 m.

Dunigan, E.P., R.A. Phelan and Z.H. Shamsuddin, Use of water hyacinths to remove
1975 nitrogen and phosphorus from eutrophic waters. Hyacinth Control J., 13:59-61

Glass-house and field trials were arranged to measure the uptake of nitrogen and phosphorus by water hyacinths from water having varying concentrations of N and P. The N was added as ammonium chloride and potassium nitrate. The N and P concentrations at the beginning of the trials were arranged to be 50, 100 and 250 ppm. After 21 days all the ammonium N at the lower and medium levels, and the nitrate N at the lowest level, had been taken up. About half the P at each concentration had also been absorbed. In the field trials the hyacinths increased the rate of loss of ammonium N, but were ineffective in removing nitrate N. The removal of P was low.

Dunigan, E.P., R.A. Phelan and Z.H. Shamsuddin, Can water hyacinths "eat pollution"?
1975a Compost Sci., 16(2):11

In green-house trials water hyacinth completely absorbed from water 50-100 ppm ammonium N in 15-21 days, 50 ppm nitrate N in 23 days, and 13-35 ppm phosphate P in 35 days. The N:P uptake ratio was about 5:1. Evapo-transpiration from the hyacinths exceeded transpiration from eutrophic waters by 320% and hastened recycling of chemically pure water back into the natural hydrological cycle. (From Weed Abstracts)

Fekete, A., D. Riemer and H.L. Motto, Removal of Rhizoclonium from a pond and its
1972 relationship to dissolved nutrients. Proc.Northeast.Weed Sci.Soc., 26:193-6

A small pond (.03 ha) was infested with the filamentous alga Rhizoclonium sp. Over two months in the summer the weed was raked out, weighed, and analysed for N and P (see Chapter III). At the same time the water in the pond was similarly analysed. The amount of N removed in the tissues of the alga was equivalent to a concentration of 23 ppm in the total pond water. Yet the maximum content determined at any time in the pond water was 4.1 ppm. Similarly, the amount of P removed by the alga was equivalent to a concentration of 1 ppm of P in the pond. Yet water analysis never revealed a P concentration of more than 0.04 ppm. Thus the N levels in the pond were apparently replenished from bottom sediments, or ammonia in rain water, or N fixation, or all three. The P levels in the water were presumed to have been restored from reserves in the bottom sediments. The authors conclude:

(a) Large amounts of N and P can be removed from a pond by harvesting filamentous algae.

(b) The effect on dissolved N and P levels in the water may be slight in relation to the amount removed, due to a continuous resupply.

(c) Continual removal of the algae may alter the condition of the pond so that only a limited amount of algal regrowth will occur.

Fekete, A., D. Riemer and H.L. Motto, A bioassay using common duckweed to evaluate
1976 the release of available phosphorus from pond sediments. J.Aquat.Plant Manage., 14:19-25

Under laboratory conditions Lemna minor was used to measure the release of P from pond sediments. It was found that the growth characters of L. minor (frond numbers, frond diameter, root length and dry weight) consistently reflected P concentrations in solution. Different sediments with high, medium and low P content were

incubated under aerobic and anaerobic conditions. The greatest amount of P extracted by the test plant was from the sediments with high P content and incubated under aerobic conditions. The results obtained, using the bioassay with L. minor, proved superior to purely chemical analyses carried out at the same time.

Fitzgerald, G.P., 1969 Field and laboratory evaluations of bioassays for nitrogen and phosphorus with algae and aquatic weeds. Limnol.Oceanogr., 14(2):206-12

Techniques are described for detecting conditions of surplus, or limiting concentrations of, nitrogen and phorphorus in algae and aquatic plants. The report also discusses a simple method for measuring rates of nitrogen fixation by blue-green algae. The test plants used were Ceratophyllum sp., Cladophora sp., Hydrodictyon sp., Aphanizomenon sp., Microcystis sp., Anabaena sp. and Nostoc sp.

The author writes that aquatic plants which have been recently exposed to a relatively high concentration of available P could absorb enough to indicate surplus P conditions by their total P content. This difference could be used to advantage in ecological studies of the effects of high dosage of nutrients or accidental spills in river systems since the relative rate of growth of plants would be a function of the time required for their enzymatic activity to decrease to its lowest level.

Golueke, C.G. and W.J. Oswald, 1965 Harvesting and processing sewage grown algae. J.Water Pollut.Control Fed., 37(4):471-98

A detailed description is given of trials, both in the laboratory and in the field, to overcome the problems of harvesting algae from sewage effluent. The principal species considered were Scenedesmus and Chlorella. Flocculation, flotation, straining, filtration, centrifugation, and gravity separation were among the methods tested. Drying the slurry was also considered, especially by means which would not impair the quality of the resultant product as an animal food. The following is a summary of findings from the trials.

Harvesting involves three steps: initial concentration which brings algal solids to 1-2% of the slurry, dewatering (secondary concentration), and final drying.

Chemical precipitation and centrifugation were the best for the initial process, though the latter is expensive in equipment and power. The best flocculating agents were alum, lime and synthetic organic polyvalent cationic polymers. Alum is needed at a rate of from 40-120 mg/litre, the higher the dose the cleaner the effluent. Freshly hydrated lime requires 100-200 mg/litre. Complete removal of algae was achieved using a polymer (Sondellite) at 2.4 mg/litre.

Dewatering the slurry was done successfully with a modified industrial gravity filter with two hatch type centrifuges and a continuous solid bowl centrifuge. Dewatering and drying can be done at the same time on specially prepared sand beds. On a typical summer day 1 470 m^2 of bed per hectare of pond is required. Otherwise drying as a thin film on a heated drum is the best method. This process improves the digestibility of the algal product and at the same time sterilizes it.

The authors conclude that the question as to whether harvesting and processing of algae grown in sewage is worth while depends on whether there is a profitable market for the product and/or for the reclaimed water. If there is, then communities forced by rigid water pollution control requirements to undertake tertiary treatment should consider algae production as an early and ultimate step in their waste disposal systems.

Haller, W.T., E.B. Knipling and S.H. West, Phosphorus absorption by, and distribution
1971 in, water hyacinths. Proc.Soil Crop Sci.Soc.Fla., 30(1970):64-8

Water hyacinth was grown in the laboratory in culture solutions containing phosphorus at varying concentrations. The P concentration critical for maximum growth was 0.1 ppm. Below this level growth was limited, above it the hyacinths took up P in luxury amounts without any increase in yield. (From Weed Abstracts)

Haller, W.T. and D.L. Sutton, Effect of pH and high phosphorus concentrations on growth
1973 of water hyacinth. Hyacinth Control J., 11:59-61

The growth of water hyacinth in nutrient solutions of different pH and P content was measured. It was found that pH between the wide limits of 4.0 and 8.0 did not appear to have any obvious influence on growth. The P content had a great effect on growth rate, morphology of the plant, and the distribution of P within the plant tissues. When grown in solution without P the plant roots developed until their total proportion to plant size was twice that of hyacinths growing in solutions containing P. The roots also became iridescent blue in contrast to the normal grey-black colour. Growth increased with P content of the solution up to a P concentration of 20 ppm. At 40 ppm growth declined and the effect of increasing P was increased toxicity to the plants. The P content of the plants with rising P concentration is shown, together with P distribution in the plant, in the following table:

P concentration of nutrient solution (ppm)	P content of water hyacinth (mg/g dry weight)			
	Leaf	Stem	Root	Whole plant
0	1.17	0.71	0.96	0.98
5	4.96	3.00	1.97	3.77
10	6.77	4.80	3.12	5.52
20	8.16	6.73	6.05	7.22
40	8.80	9.30	9.26	9.07

As the P concentration in solution becomes greater it can be seen that the distribution of P within the plant becomes more uniform. At low concentrations more P accumulates in the leaves compared to the stem and roots. It was noted that the P uptake increased in the hyacinth even after some toxic effect of the high concentration in the nutrient solution (40 ppm P) had become evident in reduced growth. This "luxury consumption" appeared to be approaching its limit for plants growing in 40 ppm P.

The authors comment: "High P absorption together with the high productivity of water hyacinth indicates that these plants could be beneficial in removing large amounts of nutrients from eutrophic waters by mechanical harvesting. The cost of this is prohibitive but it would be worth while to know the value of removing nutrients from a body of water and then including this value in determining the economic feasibility of the operation."

Kohl, W., The bacterial colonization of aquatic plants. Proc.Eur.Weed Res.Counc.Int.
1974 Symp.Aquat.Weeds, 4:31-6

The author reviews the extent and species distribution of bacteria on aquatic vegetation and their importance in water purification in Austria, and also in the breakdown of organic matter from dead vegetation and as indicators in the assessment of water quality. (From Weed Abstracts)

Lawrence, J.M. and W.W. Mixon, 1970 Comparative nutrient content of aquatic plants from different habitats. Proc.Annu.Meet.South.Weed Sci.Soc., 23:306-10

Three aquatic plants were grown in water with different degrees of pollution, from raw sewage to unpolluted. The uptake of nutrients was analysed (see Chapter III). "Luxury consumption" of nutrients was observed from water containing large amounts of N, P and K. The authors conclude: "As the availability of the nutrient changes so does the concentration of nutrient in the plant. This occurs to a far greater extent than the plant can physiologically utilize. Yet such plants retain a similar healthy external appearance to those growing with normal levels of nutrient content."

Mackenthun, K.M., 1962 A review of algae, lakeweeds and nutrients. J.Water Pollut.Control Fed., 34:1077-85

This comparatively early paper discusses the relationship of nutrients in water to algae and aquatic plants. Commenting on the amounts of nutrients released into water the author states: "The annual contribution of nitrogen and phosphorus from domestic sewage per head of population is about 1.9 kg of N and 0.5 kg of P. This is sufficient N to fertilize 0.4 ha of lake water to a depth of 1.6 m in respect of N, and 2.8 ha of lake to the same depth in respect of P to such an extent that nuisance algal blooms might occur during summer months." He points out that high nutrient concentrations in water can be substantially reduced by the passage of water through a lake, nutrient removal being influenced by temperature, biological activity and flow. The slower the flow and the longer the retention time, the greater the removal. No direct reference to the part played by aquatic plants in the removal is made except: "The temporary control of excessive aquatic growths is often a necessity for the full recreational utilization of the water. Certainly the most adequate form of control would be complete removal from the lake basin, thus removing those nutrients which are combined with biological growth. Unfortunately this is now impractical in most cases and, in other instances, such mechanical control may be laborious, time consuming and expensive. Thus attention has been focussed on the use of chemical methods for temporary control of aquatic nuisances."

That the author considers this attitude unsatisfactory is clear from his final paragraph: "The growth and development of established aquatic plants will depend on the available nutrients in the water, suitable climatic conditions and competition with other species. The void created by the destruction of one type of biological growth may be filled by another and different type of biological activity."

Mackenthun, K.M., 1971 Nutrients and their relationship to weed and algal growths. Hyacinth Control J., 9(1):58-61

The author reviews the relationship and importance of aquatic plants to their habitat. When the growth of these plants is stimulated in some manner so that they interfere with water use then a public outcry develops. The various nuisances which excessive water plants can cause include unpleasant smells and taste, toxicity to man and animals, and other negative effects on the environment, as well as physical impediments to water use.

Reviewing the literature on eutrophication (the enrichment of water by various nutrients) he points out the importance of phosphorus, which can vary greatly in concentration in water depending on the degree of contamination from agricultural or urban areas. On the question of algal populations in relation to P concentration he writes: "Growth of algae in sewage has been reported in the laboratory at 1-2 g/l (dry weight), and in sewage ponds at 0.5 g/litre. Thus, assuming optimal growth conditions, and maximum phosphate utilization, the maximum algal crop that could be

grown from 1 kg of P would be 1 tonne of wet algae under laboratory conditions or 250 kg in the field. If a cellular content of P in algae is 0.7% then 1 kg of P could be distributed among 1 450 kg of algae (wet weight). This suggests that to prevent biological nuisances total P in flowing water should not exceed 100 µg/l, and in standing water not more than 50 µg/litre."

Nichols, D.S. and D.R. Keeney, 1976 Nitrogen nutrition of Myriophyllum spicatum: variation of plant tissue nitrogen concentration with season and site in Lake Wingra. Freshwat.Biol., 6(2):137-44

The nitrogen content in Myriophyllum spicatum from different sites in a hypereutrophic lake in Wisconsin, U.S.A. was determined. From all sites the N concentration in the water was similar, but it differed in the sediments. And the N content of the plant varied in relationship to the N in the sediments, indicating a dependence on the sediment for this nutrient (which is understandable because it is a rooted plant). The concentration of N in the plants was highest in spring, decreased steadily during the summer, and increased again in the autumn. The plant grows very little during the winter but continues to accumulate N. The death and decay of a considerable portion of the plant in autumn contributes only insignificant amounts of N to the lake water. (From Weed Abstracts)

Ornes, W.H. and D.L. Sutton, 1975 Removal of phosphorus from static sewage effluent by water hyacinth. Hyacinth Control J., 13:56-8

Water hyacinth was grown outdoors in concrete tanks containing sewage effluent. Over a period of five weeks the uptake of P was measured as 5.5 mg/g of the dry weight of the plant. The P concentration in the effluent was 1.4 mg/litre at the start of the experiment and was reduced to 0.2 mg/litre at the end. Of this decrease 70% took place in the first two weeks and 80% by the end of three weeks. The hyacinth increase in (dry) weight was at a maximum during the first week and totalled 97 g/m^2 of water surface, which represented a 45% increase in the dry weight of the plants at the start of the experiment. The authors conclude that this study indicated that water hyacinths could be used to reduce P in sewage effluent to low levels. However the length of time involved may not make this a practical method because of the space required to hold the sewage effluent under static conditions. For example, to hold the sewage effluent from one day's production of a treatment plant processing 3.8 million litres/day would require a surface area of 8 190 m^2 with a depth of 0.5 m. A more practical approach would be to grow the plants in a sewage lagoon and then harvest when growth and nutrient content of the water hyacinth is maximum. This study suggests that weekly harvests of water hyacinths for one year, from sewage effluent renewed weekly, would result in growth of hyacinths of 5 kg dry weight/m^2. Based on this amount of dry weight these plants would contain 0.9 kg of crude protein and 22 g of P. The plants could then be used for mulch, soil amendment or other purposes.

Rao, K.V., A.K. Khandekar an D. Vaidyanadham, 1973 Uptake of fluoride by water hyacinth, Eichhornia crassipes. Ind.J.Exp.Biol., 11(1):68-9

The authors were interested in the possibility of using water hyacinth for extracting fluorine from water. They analysed plants growing in a reservoir which had a fluorine content of 1.0 ppm. The plants were found to have 23 ppm F in the leaf and 60 ppm F in the petiole.

Hyacinths were then grown in nutrient solution to which a range of concentrations of sodium fluoride had been added. Over four weeks the uptake of fluoride by hyacinth plants was measured. Over a range of concentrations of 6 ppm to 26 ppm fluoride, the plants (each about 150 g) took up from 11 to 75 mg of fluoride. However the authors conclude that the efficiency of uptake was too low for hyacinth to be considered of practical use in extracting fluorine from the typically low concentration present in natural waters.

Reay, P.F., 1972 The accumulation of arsenic from arsenic-rich natural waters by aquatic weeds. J.Appl.Ecol., 9(2):557-65

Several aquatic plants have been found to accumulate arsenic from the Waikato river in New Zealand to levels well above those associated with toxicity of this element. The species examined differed in the concentration to which they accumulated arsenic, and the average values ranged from 30-650 mg/kg dry weight. Accumulation was influenced by the amount of arsenic in the water but not by the amount in the river and lake bottoms (for details see Chapter III).

Rogers, H.H. and D.E. Davis, 1971 Nutrient absorption from sewage effluent by aquatic weeds. Proc.Annu.Meet.South.Weed Sci.Soc., 24:352 (Abstr.)

Eichhornia crassipes (water hyacinth), Alternanthera philoxeroides and Myriophyllum spicatum were grown for two months in plastic pools containing water with or without added sewage effluent. Similar control pools contained no plants. Nitrogen and phosporus concentrations were measured at intervals. The sewage-enriched water initially contained five times as much N and three times as much P as unenriched water. Six days after planting the N content in sewage-enriched water decreased to less than 10% of the original value. During the same period the N content in unplanted pools with sewage-enriched water decreased to about 20%. P concentrations did not decrease as rapidly as the N concentration, and the effect of plants on depletion was not as great. The experiment was impaired by an unknown disease which killed many of the water hyacinths. A. philoxeroides tolerated the low fertility of unenriched water better than the other two species. (From authors' abstract)

Rogers, H.H. and D.E. Davis, 1972 Nutrient removal by water hyacinth. Weed Sci., 20(5):423-8

In laboratory experiments the uptake of N and P by water hyacinth was measured in static and in flowing water. The nutrients were either added as sewage effluent or as a standard solution (Hoagland's) which at 10% strength contains 3 mg/l P and 22 mg/l N, equivalent to the sewage effluent which had 3.6 mg/l P and 22 mg/l N. Measurements of N and P uptake by the hyacinth per day at various concentrations of Hoagland's solution and sewage effluent, in flowing and in static water, are tabulated below.

Uptake by individual hyacinth plants (mg/day)

	Still water		Flowing water	
Solution	N	P	N	P
10% Hoagland's	5.3	1.1	9.9	1.7
25% Hoagland's	11.4	2.1	18.4	2.5
50% Hoagland's	19.8	3.1	20.8	3.3
Sewage effluent	6.6	1.6	-	-

On the basis of an estimate by Lee (1970) that the annual domestic waste per person is 0.9 kg P and 3.2 kg N, and another estimate (Penfound and Earle, 1948) that 1 ha of water hyacinth contains about 1.62×10^6 plants it is assumed that 1 ha of water hyacinth could absorb the N and P wastes of 800 people. This assumes a maximum uptake and growth by the plants throughout the year. The authors suggest that consideration be given to growing hyacinths under a plastic roof both to extend its growing season and also to enable transpired water to be condensed for reuse, or to dilute the effluent. A further means of promoting hyacinth growth would be to make use of the waste hot water from power stations.

Transpiration by individual hyacinth plants, per day, averaged 175 ml from still water and 225 ml from flowing water.

Scarsbrook, E. and D.E. Davis, 1970 The effect of sewage effluent on growth of five aquatic species. Proc.Annu.Meet.Weed Sci.Soc., 23:305 (Abstr.)

Eichhornia crassipes, Alternanthera philoxeroides, Egeria densa, Najas flexilis and Potamogeton crispus were grown in plastic pools in well water, with or without the addition of 25% of sewage effluent. Of the five test plants, E. crassipes showed the maximum growth response to the sewage effluent, with A. philoxeroides second. In well water alone A. philoxeroides was the only plant to survive, indicating its ability to tolerate very low nutrient levels. (From Weed Abstracts)

Scarsbrook, E. and D.E. Davis, 1971 Effect of sewage effluent on growth of five vascular aquatic species. Hyacinth Control J., 9(1):26-30

The growth of five aquatic plants in well water to which sewage effluent had been added was recorded together with their uptake of nitrogen, phosphorus and potassium. The plants were Eichhornia crassipes (water hyacinth), Alternanthera philoxeroides, Potamogeton crispus, Egeria densa and Najas flexilis. The tests were in plastic pools 66 cm deep and 2.7 m in diameter containing no soil. A mixture of all the plants was put in each pool. Half the pools had 25% sewage effluent, the others well water only. In the latter pools all the test plants died except A. philoxeroides, but its growth was stunted and unhealthy.

In the sewage-treated pools, by the end of 11 weeks water hyacinth had dominated all the other species and had covered 71% of the water surface. The next in vigour was A. philoxeroides, though its growth was much less than water hyacinth. The other test plants did not grow sufficiently in face of the competition to justify harvesting. The results are shown in the following table:

Growth over 23 weeks (April-October) - g dry weight

Plant	Initial weight	Harvested weight	
		Well water only	25% sewage effluent
E. crassipes	2.0	59.0*	736.6*
A. philoxeroides	0.6	7.9	20.4
P. crispus	0.5	0.9	4.7
E. densa	0.2	0.0	0.0
N. flexilis	0.1	0.0	0.0

* Includes weight of plants harvested at 11 weeks.

The water hyacinth had removed 6.9 g of N, 2.9 g of P and 8.7 g of K from the sewage pools. A. philoxeroides did not gain N and K, instead the plants released these elements to the water; but they took up some P (0.15 mg). The authors conclude that water hyacinth could be usefully employed to extract nutrients from sewage.

Sheffield, C.W., Water hyacinth for nutrient removal. Hyacinth Control J., 6:27-30
1967

In a literature review the author cites findings that the P content was 0.22 mg/l in the effluent from a biological treatment sewage system. Trickling filters cannot remove P but they can remove about 10% of the total N content. By the activated sludge process 10-90% of N can be removed, depending on the temperature and loading rates employed. One plant reported up to 95% P removal by a modified activated sludge system, but this result was considered exceptional.

Considering the alternative approach of using water hyacinth as a means of nutrient removal from effluent the author cites the claim of Van Vuran (1948) that water hyacinths could remove annually, under ideal conditions, 3 400 kg of N per hectare of water surface.

In the laboratory, treatment of sewage effluent by an algal pond system was compared with water hyacinth having an air stripping and coagulant system, in terms of efficiency in removing nitrate N, ammonia N, and P. The results were tabulated:

Process	Nitrate N		Ammonia N		Phosphate	
	Final effluent concentration (mg/l)	% removal	Final effluent concentration (mg/l)	% removal	Final effluent concentration (mg/l)	% removal
Algal pond	5.0	67	7.0	88	1.0	99
Hyacinth pond	0.2	99	0.1	99+	0.7	99+

The author points out that the water hyacinth system was far superior to the algal pond when air stripping and coagulation techniques were included. He states that without them the hyacinth initially removed 50% of the P or better. Then as more and more bottom settlements occurred within the pond the phosphates seemed to recycle back into the water resulting in only 10-15% P removal.

Steward, K.K., Nutrient removal potentials of various aquatic plants. Hyacinth Control
1970 J., 8(2):34-5

This paper reviews the effectiveness of different aquatic plants in extracting nutrients from polluted water (for details see Chapter III). Steward writes: "Nitrogen and phosphorus are present on average in plant tissues at a ratio of 10:1. This is the ratio at which these elements often occur in natural waters." He cites evidence that N and P are entering waters at a ratio of nearly 5:1. In domestic sewage the ratio is 3:1. Thus plants can only remove one third to one half of the P, since N supplies would be limiting. He calculates that water hyacinth, with a theoretical productivity of 165 t/ha, could effectively remove the yearly contribution of N from 1 430 people and thus P from only 450 people. He quotes unpublished reports of the sucessful control (in the U.S.A.) of eutrophication in a small lake by growing water hyacinth in a fenced area in the centre of the lake. After one year the lake was clear and supporting fish.

Another report (from Germany) states that Juncus lacustris has been used to purify industrial effluents on a massive scale. The effluents flowed at a rate of 5 million m^3/day through 20 basins each 400 m long x 50 m wide.

Sutton, D.L. and W.H. Ornes, Phosphorus removal from static sewage effluent using duck-
1975 weed. J.Environ.Qual., 4(3):367-70

The duckweeds Lemna gibba and L. minor were grown (200 g fresh weight/m^2) in secondary treated sewage effluent diluted to 6, 12 and 25% concentration. These concentrations gave increases of growth at 16, 23 and 31% higher than plants grown in pond water. Increasing the sewage concentration did not further increase the growth rate. Over eight weeks of the experiment the P content in the sewage decreased by 97%. The P content in the plants continued to increase with higher concentrations of P in the sewage until the sewage concentration of P reached 2.1 mg/litre; then the P content of the plants began to decline.

Protein content of the plants grown in 50% and 100% effluent was almost three times that of plants grown in pond water. The protein content of the plants rose rapidly to about 40% during the first week and then declined to about 12% at the fourth week, and then remained at about the same level for the remaining four weeks of the experiment.

The authors conclude: "This study indicated that duckweed could be used to reduce P to low levels in sewage effluent held under static conditions. The rate of P removal would depend on the amount of duckweed, concentration of P in the effluent, and length of contact time."

Telitchenko, M.M., G.V. Tsttsarin and Ye.L. Shirokova, Trace elements and algal "bloom".
1970 Hydrobiol.J., 6(6):1-6

The authors point out that trace elements in water are responsible for massive increases in numbers of different species of algae - the so-called "bloom". It was established that Aphanizomenon flos-aquae and Microcystis aeruginosa (Cyanophyceae) concentrate 18 trace elements from water, one of which is copper. When copper stocks are exhausted the "bloom" of Cyanophyceae in the water ceases. Repeated blooms are noted only when the water is enriched with copper by the death of the previous generation of algae. A conclusion, therefore, is that algal bloom should not be controlled by treatment with copper sulphate, though some algae (e.g. Spirogyra) are extremely susceptible.

Timmer, C.E. and L.W. Weldon, Evapotranspiration and pollution of water by water hyacinth.
1967 Hyacinth Control J., 6:34-7

The growth of water hyacinth will pollute water by adding to it particles of decaying tissue. With evaporation tests the authors measured 3.7 times greater evaporation of water under hyacinth than from clean water, thus confirming earlier similar findings (Penfound and Earle, 1948). These factors need to be taken into account when considering the use of hyacinths to remove pollutants from water.

Note: These findings were similar to those of Little (1967) who recorded, from glasshouse tests in the United Kingdom, that the rate of evapotranspiration of water hyacinth with leaves 30-40 cm long was 4-5 times that from the surface of open water under simulated tropical conditions. He commented: "It seems likely that with the much larger and more vigorous plants, commonly found in the tropics, rates of evapotranspiration may even exceed the up to six times normal reported by Penfound and Earle (1948)". Little also found that Pistia stratiotes (leaves 10 cm long) had an increased evapotranspiration rate of 2-3 times that of open water. Salvinia auriculata gave only a slightly increased rate (but its speed of growth was well below that normal in the tropics).

U.S. National Aeronautics and Space Administration, Aquatic blooms as problem solvers.
1976 NASA Activ., 7(8):22-4

This NASA news publication reports on experiments with water hyacinth to purify sewage. An extract is given below.

Water hyacinths were enclosed on a 16-ha lagoon which received sewage from 6 000 households. The plants soon grew at a rate of 20-40 t/ha/day fresh weight. It was found that an area of about 5 ha of water hyacinth was more than enough to purify the lagoon.

The cost of a standard chemical filtration plant to remove waste products from a sewage lagoon of a small community, to meet current pollution standards, would be about US$500 000. Experiments using water hyacinths have shown how adequate water purification standards could be achieved at a cost of only the few thousand dollars needed for stocking and repeatedly harvesting the plants.

Effluent containing industrial and chemical waste flowing at a rate of about 60 000 litres/day has been purified by water hyacinths growing in a zig-zag canal type lagoon, 12 m wide x 0.8 m deep and 250 m long, to a level exceeding effluent standards.

A system is being proposed by which an assessment of heavy metals present in various water bodies may be made by analysis of the plants growing in the water rather than the water itself.

It has been found that duckweed can be used as a supplemental filtration system to water hyacinth. When surface quantities of hyacinth diminished in cold weather the amounts of duckweed increased and continued to absorb nutrients from the water, though at a reduced rate. When temperatures rose and hyacinths increased again the duckweed reduced in number.

The results of the various aspects of this research programme at NASA have stimulated a number of similar experiments in other regions in the U.S.A. and in other countries.

U.S. National Space Institute, Will hyacinth become first moon flower? Natl. Space Inst.
1976 Newsl., U.S., 1(9):6

This Newsletter refers to a proposal that water hyacinths should be included in space experiments to purify wastes in space ships. Growing in a tank containing about 10 m^3 of water, the plants should purify the wastes of 10 people.

Wahlquist, H., Production of water hyacinths and resulting water quality in earthen
1972 ponds. Hyacinth Control J., 10:9-11

The response of water hyacinth to added fertilizer in ponds was measured. One observation was that ponds treated with fertilizer, but without hyacinth, had a rich, dark green bloom of plankton. Similarly treated ponds with hyacinth had clear water, or only a light plankton population. It was concluded that hyacinths were more successful at extracting nutrients than the algae. The author cites Penfound and Earle (1948) as having measured a yield of water hyacinth of 414 t/ha. In the trials reported here the yield without fertilizer would have been 175 t/ha; with P only added, 550 t/ha; with N and P both added, 590 t/ha. Wahlquist suggests that these results indicate the potential value of hyacinth as a means of alleviating the pollution of eutrophic waters.

Widyanto, L.S., 1975 The effect of industrial pollutants on the growth of water hyacinth (Eichhornia crassipes). Tropical Pest Biology Program, BIOTROP, Bogor. Proc.Indonesian Weed Sci.Conf., 3:328-39

A survey of the waste water of four textile factories revealed that in two factories the total dissolved solids was higher (1 185 and 1 204 mg/l) than the acceptable concentration of total dissolved solids (1 000 mg/l) in water for domestic and irrigation purposes. The sulphate content of the water in one case was so high (719 mg/l) that water hyacinth died after five days when grown in it, or even when the impure water was diluted by 50%.

Dilution of the waste from another factory (concentration not stated) had the effect of stimulating hyacinth growth. This suggests that, with appropriate dilution of factory waste waters, hyacinth could be used to purify such waters for reuse or for crop irrigation.

Wolverton, B.C., 1975 Water hyacinths for removal of cadmium and nickel from polluted waters. NASA Tech.Memo., (TM-X-72721):11 p. Issued also in Sci.Tech.Aerospace Rep., 13(7):795-6

The author points out the hazards to health from the release of heavy metals like cadmium and nickel to waterways in industrial effluents. He notes the efficiency of water hyacinth in extracting a range of elements from water, and describes laboratory experiments to measure its extraction capacity for cadmium and nickel. It was found that, within 24 hours, hyacinths were able to absorb and concentrate in their roots: cadmium up to 0.67 mg/g dry matter, and nickel up to 0.5 mg/g dry matter from water polluted with 0.6-2.0 ppm of these metals.

The roots represent about 18% of the total dry weight of the hyacinths, and in them was found 97% of the heavy metals absorbed by the whole plant. No toxic effects from the heavy metal concentration in the water was observed in the plants. It was concluded that, as 1 ha of hyacinth has an approximate growth rate of 600 kg/dry matter/day, the plants could potentially remove about 300 g of heavy metals from 1 ha of polluted water per day.

Wolverton, B.C., 1975a Water hyacinth for removal of phenols from polluted waters. NASA Tech. Memo., (TM-X-72722): 18 p. Issued also in Sci.Tech.Aerospace Rep., 13(7):795

Phenol and phenolic derivatives are common organic pollutants in domestic and industrial wastes, and in drinking water. In addition, chlorophenols, which have an extremely objectionable odour and taste, are produced by chlorination of drinking water when it is contaminated with phenolic compounds. Laboratory trials are described which measured the ability of water hyacinth to extract phenol from water to which known amounts of phenol (25, 50 and 100 ppm) had been added. Tests were carried out in both distilled and river water. It was found that the hyacinths were able to extract phenol from water at a rate of 36 mg/g dry matter in 72 hours. On a basis of 1 ha of water surface carrying 1.62×10^6 plants, with an average dry weight each of 2.75 g, it was calculated that 1 ha of water hyacinth would extract 160 kg of phenol in 72 hours.

No phenol could be detected in any part of the hyacinths which achieved this extraction. Also no evapotranspiration of phenol could be measured. Therefore it was concluded that the phenol, as it is removed from the water by the hyacinths, is rapidly metabolized to other components. None of the concentrations of phenol used appeared to adversely affect the hyacinths.

Wolverton, B.C. and D.D. Harrison, Aquatic plants for removal of mevinphos from the 1975 aquatic environment. J.Miss.Acad.Sci., 19:84-8

In laboratory trials Nymphaea odorata, Paspalum distichum and Juncus repens were used to evaluate the effectiveness of aquatic plants in removing the insecticide mevinphos from waters contaminated with this chemical (at 43-58 ppm). The emergent plants N. odorata and P. distichum removed 93 and 87 ppm of mevinphos, respectively, from the water in less than two weeks without apparent damage to the plants. J. repens, a submerged plant, removed less insecticide than the controls which contained contaminated water and soil only. The controls still contained toxic levels of the insecticide after 35 days, as detected by fish bioassay studies.

The authors speculate that the filtering capability of aquatic plants depends on absorption, translocation, concentration and detoxification by metabolic breakdown. Emergent aquatic plants may be more effective in removing mevinphos than submerged species because of the quantity of water they transpire.

Wolverton, B.C. and R.C. McDonald, Water hyacinths and alligator weeds for removal of 1975 lead and mercury from polluted waters. NASA Tech.Memo., (TM-X-72723)

Following successful trials on the uptake of nickel and cadmium by water hyacinths (Wolverton, 1975) further glass-house tests with this plant to measure uptake of lead and mercury were carried out. The work was expanded to include also Alternanthera philoxeroides (alligator weed) which is known to tolerate higher levels of salinity than hyacinths.

It was found that, during a 24-hour period, the following maximum amounts of metals were extracted by the plants from water containing initially 1.09 ppm lead and 0.875 ppm mercury:

	Metal removed (mg/g dry matter/day)	
Plant	Lead	Mercury
Water hyacinth	0.176	0.15
Alligator weed	0.101	0.153 (6-hour period)

It was concluded that, at these rates and under a continuous harvesting system, it is possible for water hyacinths to remove 105.6 g of lead and 90.0 g of mercury per day from 1 ha of polluted water.

Wolverton, B.C. and R.C. McDonald, Water hyacinths and alligator weeds for removal of 1975a silver, cobalt, and strontium from polluted waters. NASA Tech.Memo., (TM-X-72727)

Eichhornia crassipes (water hyacinth) and Alternanthera philoxeroides (alligator weed) were grown in the laboratory in distilled water and in river water. To the water was added (in separate containers) known amounts of silver nitrate, cobalt chloride and strontium nitrate in order to measure the ability of the test plants to take up these metals, which are often pollutants in waste water. The concentrations of these elements in the test solutions were:

Ag 0.6-2.4 ppm; Co 0.5-2.0 ppm; Sr 0.4-2.0 ppm

It was found that water hyacinths were able to remove about 0.44 mg Ag, 0.57 mg Co and 0.54 mg Sr per g of plant dry matter in 24 hours.

Extrapolating to field conditions the authors conclude that the test plants could potentially extract 263 g Ag, 341 g Co, and 326 g Sr per hectare per day "provided that the metal-saturated plants are harvested at regular intervals."

Alligator weeds removed a maximum of 0.44 mg Ag, 0.13 mg Co, and 0.16 mg Sr per gram of plant dry matter per day.

Wolverton, B.C. and R.C. McDonald, 1975b Water hyacinths for upgrading sewage lagoons to meet advanced wastewater treatment standards. Part 1. NASA Tech.Memo., (TM-X-72729)

A field trial to measure the ability of water hyacinth to purify the water of a secondary sewage lagoon is reported.

In their introduction the authors state that water hyacinth is an easily harvested plant which possesses adequate levels of mineral and protein for it to be grown as a crop in warm climates for use in many ways. In temperate conditions it could be used in conjunction with hydroelectric generating stations. Thermal discharges from the condenser cooling water could be mixed with sewage pumped into large lagoons nearby and water hyacinths grown there throughout the year in the warm, nutrient-enriched water. The method could also utilize the waste hot water from nuclear power plants. In this role hyacinths could also provide a safeguard to absorb radioactive isotopes should they be accidentally released into the waste water.

The trial ran for three months in the summer. It was found that effluent entering the lagoon had a N content of about 3 ppm. After passing through the hyacinths the water leaving the lagoon had about 1.2 ppm N, a recuction of about 60%. The P inflow concentration was 5.5 ppm, which reduced to 4.1 ppm for the first five weeks (26% removal). The authors state that phosphorus reduction rates after this period of time suggest that plants should be harvested at 5-weekly intervals for maximum P removal.

It was concluded that based on data presented in this preliminary report, cities located in the tropical and subtropical regions of the world should be able to utilize water hyacinths as a final filtration system for reducing the levels of polluting substances in domestic sewage to levels which comply with advanced waste water treatment standards. For nearly complete removal of P an area of about 4 ha would be needed per 5 000 people. But complete removal of P is not usually required, or even desirable. Therefore much smaller systems could be used to meet present and future waste water effluent standards.

Wolverton, B.C. and R.C. McDonald, 1976 Don't waste waterweeds. New Sci., 71(1013):318-20

This popular review article reports on the work being done at the National Space Technology Laboratories on the usefulness of water hyacinth for purifying water.

The authors state that when grown in warm enriched domestic sewage water hyacinths produce over 17.8 tonnes of wet biomass per hectare per day. Such plants contain 17.2% crude protein, 15-18% fibre and 16-20% ash, with the following analyses:

Element	% Dry weight
C	32 to 35
H	5.4 " 5.8
N	2.8 " 3.5
K	2.0 " 3.5
Na	1.5 " 2.5
Ca	0.6 " 1.3
P	0.4 " 1.0
S	0.3 " 0.4
Mg	0.2 " 0.3
Fe	0.03 " 0.05
Zn	0.005 " 0.05
Mn	0.005 " 0.008

Growth rates suggest annual production rates of 212 tonnes of dried plant material per hectare.

Raw sewage from small Mississippi communities contains an average of 35 ppm of N and 10 ppm P. On this basis a 0.5-ha lagoon covered with water hyacinths, with a minimum sewage retention time of two weeks, should be able to purify to acceptable levels the daily waste of 1 000 people. An experimental lagoon did reduce pollutant levels by 75-80%.

Water hyacinths could also prove useful in treating effluents polluted with toxic heavy metals. In static laboratory experiments the plants rapidly absorbed gold, silver, cobalt, strontium, cadmium, nickel, lead and mercury. The roots concentrated 97% of the Cd and N within 24 hours, though having only 18% of the plants' total dry weight. Water hyacinths can also absorb, or metabolize, phenols and other trace organic compounds of the type commonly found in the drinking water supplies of many large cities.

Duckweeds are being tested as a means of sewage filtration during cold months when water hyacinth is temporarily inactive.

Wolverton, B.C., R.C. McDonald and J. Gordon, Water hyacinths and alligator weeds for
1975 final filtration of sewage. NASA Tech.Memo., (TM-X-72724)

Eichhornia crassipes (water hyacinth) and Alternanthera philoxeroides (alligator weed) were grown for two weeks in laboratory conditions, in sewage water taken from the inflow and outflow of a wastewater lagoon. Analyses of the plants and water were made for nitrogen, phosphorus and a series of metals before, during and after the growth period. The results are summarized in the following tables:

Reduction in original levels of plant nutrients from sewage (%) after 14 days

Plant	Inflow water N	Inflow water P	Outflow water N	Outflow water P
Water hyacinth	92	60	75	87
Control (no plants)	18	12	15	11
Alligator weed	98	71	83	59
Control (no plants)	31	30	12	21

Heavy algal growth occurred in the control vessels but no visible algae were present in vessels containing plants.

Concentrations of heavy metals (ppm) in water initially, and in plant roots after 14 days

Source	Pb	Cd	Cu	Ag	Ni	Zn	Hg	Sr	Co
Effluent water	0.008	0.001	0.01	0.02	0.05	0.08	0.001	0.01	0.007
Water hyacinth	0.063	0.001	0.01	0.02	0.05	0.58	0.001	0.01	0.007
Alligator weed	0.035	0.001	0.16	0.02	0.05	0.84	0.001	0.01	0.007

The authors conclude that the test plants demonstrated their potential as secondary and tertiary filtration systems capable of producing clean water from sewage lagoon effluent. They were also free of toxic levels of trace heavy metals after a 2-week growth period. Therefore the harvested material, relatively high in protein and mineral content, is an excellent candidate for feed and/or food products.

Wolverton, B.C., R.M. Barlow and R.C. McDonald, Application of vascular aquatic plants
1976 for pollution removal, energy and food production in a biological system. In Biological control of water pollution, edited by J. Tourbier and R.W. Pierson, Jr. Philadelphia, University of Pennsylvania Press, pp.141-9

This article is an illustrated review of the work carried out at the U.S. National Space Technology Laboratories on the use of Eichhornia crassipes (water hyacinth) and Alternanthera philoxeroides (alligator weed) in the purification of water (the relevant papers are cited in this chapter). The authors state that the vast potential of vascular aquatic plants for removing chemical pollutants from water systems is just beginning to be fully appreciated by environmental scientists.

A diagram is shown of a zig-zag secondary sewage treatment lagoon growing hyacinths for conversion to methane production. Another illustration suggests a layout of hyacinth culture based on the effluent from livestock feed-lots and poultry farming. Harvesters extract the hyacinths from the secondary treatment lagoon for conversion to animal foods, fertilizer and methane.

Wooten, J.W. and J.D. Dodd, Growth of water hyacinth in treated sewage effluent. Econ.
1976 Bot., 30:29-37

The literature on the uses and potentials of water hyacinth, especially as a means of removing nutrients from sewage effluent is reviewed. Discussing the alternative of using algae the authors contend that there is no feasible mechanism for harvesting algae (in contrast to the simple harvesting techniques for hyacinths). Thus algae can only be utilized by harvesting higher organisms in the food web with which they are associated, i.e. fish.

In their experiments Wooten and Dodd used five ponds, each 465 m^2 in area and 0.8 m deep through which sewage effluent flowed in sequence at a rate of 480 l/min. In mid-April 2 000 water hyacinth plants were placed in the ponds. By the end of July the plants had increased to 500 000 covering the ponds completely, the weight estimated at 645 t/ha (dry weight 29.7 t/ha). This represents a growth rate (dry weight) of 29 $g/m^2/day$, and approximates to a production of 30 metric tons of organic matter per hectare in 105 days. Growth rates of water hyacinth seem to reach optimum levels when nutrients are maintained at high levels and the plants are periodically harvested to alleviate overcrowding. Thus in a climate permitting continuous growth throughout

the year more than 100 t/ha of organic matter could be produced annually, starting with a small inoculum every 100 days and with continuous harvesting under ideal conditions. Up to 150 t/ha could possibly be easily achieved, which is much higher than can be obtained with crop plants.

The rate of disappearance of N and P from each of the five ponds, as shown by analyses of the outflow waters, together with the analysis of the effluent as it came in, is shown in the following table which covers a 2-week period when the ponds were fully covered by hyacinths.

Analyses (ppm)

Date	Site	pH	NH_4 nitrogen	NO_3 nitrogen	Ortho phosphate
July 19	Main inflow	7.5	2.4	2.9	18.8
	Pond 1 outflow	7.2	2.7	4.1	17.5
	" 2 "	7.1	1.5	2.0	16.2
	" 3 "	7.0	1.1	0.9	15.6
	" 4 "	6.9	0.7	0	19.3
	" 5 "	7.0	0.5	0	16.8
Aug. 2	Main inflow	7.2	13.1	1.0	23.1
	Pond 1 outflow	7.1	9.7	2.6	28.1
	" 2 "	7.0	5.5	1.5	26.2
	" 3 "	6.9	4.2	0.8	23.7
	" 4 "	6.8	3.5	2.5	19.3
	" 5 "	6.9	0.6	0	21.0

The authors comment that these tables reflect the wide variation in nutrient content that can occur in effluents. But they have found that water hyacinth will grow vigorously in solutions containing 100 ppm N, contrary to other authors who have claimed that 25 ppm N is the concentration which gives maximum growth. Therefore the usual levels of N in sewage-enriched waters will not be high enough to inhibit growth.

Regarding P uptake, it is pointed out that the above results should be considered in the light that evaporation and transpiration water losses have occurred and have the effect of concentrating N and P in the remaining solution. Also P use by plants is less than for N and, as N is depleted, less P is absorbed. The table also shows that the hyacinths can deplete P from solutions with concentrations of up to 28.1 ppm, contrary to other workers who have found 7.5 ppm limiting. When the flow of effluent into the ponds was later stopped for two weeks the average drop in P content was found to be 40%.

The authors concluded that though their experiments suffered from various difficulties (e.g. a leak developed in pond 4),"the potential value of using water hyacinths as a type of tertiary treatment of sewage effluent is clear, and warrants a larger and more sophisticated experimental programme to define the nutrient budget of this plant. This would include experimental determination of the total growth needed to reduce phosphates to acceptable levels. It is conceivable that N or other nutrients might become limiting before the desired reduction is achieved and the addition of fertilizer might be required to maintain a balanced growth."

Yount, J.L. and R.A. Crossman, Eutrophication control by plant harvesting. Part 2.
1970 J.Water Pollut.Control Fed., 42(5):R173-83

The authors point out that the pollution of lakes can be reversed by the harvesting of fish, algae and other organisms because in this way nutrients would be removed from the lakes. Floating plants were chosen for their trials because they are the most convenient organisms to harvest, and because they can be anchored in any part of the lake. Floating plants have an advantage over submerged and planktonic plants because, being in the atmosphere, supplies of carbon dioxide are not limiting. They can also compete with algae by effectively shading them from light. The plants used were water hyacinth and Salvinia rotundifolia, and the trials were carried out in ponds fertilized with various amounts of waste water sludge containing at least 5.5% N and 3% P. To control biting mosquitoes, males and females of the fish Gambusia affinis were put into the ponds.

Growth rates of hyacinth of 21 $g/m^2/day$ were measured. The yield of various insects was also recorded. It was found that production of insects was greatest in ponds with added nutrients. Yount and Crossman suggest that when nutrients are added in small amounts algae may be more efficient than hyacinths in absorbing them and thus increase insect productivity. They suggest that by concentrating nutrients into streams, and using hyacinths to extract the nutrients there before the waters reach the lakes, the numbers of insects produced could be reduced - an important matter when biting insects are present in serious numbers.

The trials showed that the regular removal of hyacinth from test ponds effectively reduced the productivity of the water (and in consequence the growth of the test plants). The authors conclude: "We feel that large-scale harvesting from natural waters can be expected to reduce the productivity of these waters and probably reverse the trend towards hypertrophy, especially in polluted waters. Furthermore it is evident that the present method of controlling the 'pest' water hyacinth and other plants by chemical sprays is returning their contained nutrients to the lakes and exacerbating hypertrophy of these lakes."

Zafar, A.R., Economic significance of certain species of Scirpus sp. In Aquatic weeds
1976 in South East Asia, edited by C.K. Varshney and J. Rzeska. Proceedings of a Regional Seminar on noxious aquatic vegetation in tropics and sub-tropics, New Delhi, 12-17 December, 1973. The Hague, Dr. W. Junk, B.V. pp.387-91

The characteristics of those aquatic plants which may be expected to synthesize ethanol or phenol under anaerobic conditions in underground stems are listed. Such characteristics would also, it is suggested, confer on the plant the ability to absorb phenol which is often an important contaminant of industrial effluents. Some species of Scirpus, especially S. lacustris, are considered to meet the necessary criteria. These are:

(a) having rhizomes which grow buried in oxygen-deficient soil;

(b) the plant should be emergent, tall, with long stems (this minimizes oxygen transport to the rhizomes because of the distance of travel);

(c) leaves should be on the upper part of the stem only and sheathing it - again limiting oxygen transport;

(d) the stem should be without large air chambers.

S. lacustris is reported also to exude phenol from roots and rhizomes which can inhibit the growth of bacteria, a characteristic which could make the plant useful to grow for water purification in water works.

Anon., Water hyacinths help in treatment of waste water. Compost Sci., 12(5):27 1971a

Work at Iowa State University, U.S.A., with water hyacinths growing in sewage is reported. Nitrogen removal by the plants was estimated at 560 kg/ha/year. It was found that water hyacinths do well in water containing N at a concentration of up to 100 ppm. Above this concentration the hyacinths are adversely affected. A heavily used sewage lagoon might have 200-300 ppm N. A holding pond for effluent drawn from the lagoon may be down to 100-200 ppm N. Thus if hyacinths were to be grown on the ponds some adjustment of effluent dilution may be desirable, and then it may be possible to grow the plants efficiently on both types of ponds.

Advantages of water hyacinths for sewage purification are stated to include the increased evapotranspiration of water and shading of the water to reduce algal growth. A disadvantage, in colder regions, is that the population of plants may be killed off in winter by frosts thus requiring replanting of the ponds each year.

The article emphasizes the need to harvest and remove the plants from the lagoons, otherwise they will die, decay and return their contained nutrients to the water.

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XI. MISCELLANEOUS USES

This chapter includes some uses of aquatic plants not covered earlier in this handbook. There are probably many other uses which appear in the literature and have been overlooked, and many more, discovered by ingenious people in countries where every resource needs to be exploited, which have yet to be published.

The work of the U.S. National Academy of Sciences (1976) is helping to reveal and publish many of these uses. In their book there is a chapter on "Energy", and another on "Aquatic plants for food and miscellaneous uses". As the book is recent and readily available only brief reference is made herein to the wealth of information it contains.

Sculthorpe (1967) has included research into the classical literature for many useful and interesting references to the various uses to which aquatic plants were put in the past, many of which are relevant today.

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1. Fuel

Casebow, A.J., 1967 Letter to the editor on the possibility of converting of water hyacinth to methane. PANS (C), 13(3):243-4

The author suggests that in Zaire water hyacinths would be suitable for methane generation by villagers living near the river. If mixed with goat or sheep manure hyacinth could be used, for example, in a type of methane generating apparatus developed in Kenya, known as the Hutchinson methane plant.

*India, Council of Scientific and Industrial Research, 1952 The wealth of India. Vol. 3. Raw materials. New Delhi, CSIR, pp.130-4

Reviewing the uses of water hyacinth the article refers to its use for fuel.

"Many farmers in Bengal use dry hyacinth as fuel. The usual practice is to collect the plants at the beginning of the cold weather, leave them on high land to dry and use the dried material along with jute sticks and refuse as fuel. The ashes are subsequently used as manure."

"The possibility of using the dried weed for the production of power gas and power alcohol has been considered. Three methods have been suggested, viz. saccharification by acid digestion and subsequent fermentation, gasification by air and steam with recovery of ammonia, and bacterial fermentation and utilization of the evolved gas for power production. Potassium chloride (0.1 ton of KCl per ton of dry hyacinth) is recovered in all the 3 processes. Starting from 1 ton of dried water hyacinth, 13 gallons of ethyl alcohol and 0.2 tons of residual fibre (7,700 B.t.u.) are obtained by the first process. Gasification by air and steam at 800° gives, per ton of dried material, 82-116 lb. of ammonium sulphate and 40,000 cu.ft of gas (148.8 B.t.u.) containing hydrogen, 16.6; methane, 4.8; carbon monoxide, 21.7; carbon dioxide, 4.1; and nitrogen, 52.8. Bacterial fermentation gives per ton of material 26,500 cu.ft of gas (600 B.t.u.) containing: methane, 51.6; hydrogen, 25.4; carbon dioxide, 22.1; and oxygen, 1.2%. The commercial possibilities of the processes have not been proved."

Mayberry, D.H., Fertilizer and fuel from tiny plants. Agric.Res., Wash., 25(1):7 1976

The author describes the work of J.W. Newton, of the U.S. Department of Agriculture, with the blue-green alga Anabaena azollae. This nitrogen-fixing organism grows in a leaf cavity of the water fern Azolla.

If the fern is grown in the laboratory in water containing N fertilizer, or in an atmosphere free from N, or both, the N-fixing A. azolla, instead of fixing N, releases hydrogen. The amount of H released is comparable to the N-fixing activity of the alga. The author writes that although small-scale, and at a low rate, the laboratory production of hydrogen by the alga-fern system needs only water as a hydrogen source, and is not self-limiting. If hydrogen is to be considered as a fuel then the alga-fern symbiosis is particularly attractive as a system for biological production of gas.

U.S. National Academy of Sciences, National Research Council, Making aquatic weeds 1976 useful: some perspectives for developing countries. Washington, D.C. Agency for International Development, 175 p.

This book has an illustration (p.110) of an experimental biogas plant using water hyacinths. Details of optimum temperature (32-36°C), nutrient content (carbon to nitrogen ratio should be between 20:1 and 30:1), the need for regular stirring, control of acidity, and precautions to be taken are described. It is estimated that the amount of water hyacinth that can be grown in 1 ha of water could produce 70 000 m^3 of methane gas valued, at the time of writing, at about US$5 000.

Other aquatic plants such as Lemna, Myriophyllum, Hydrilla, Alternanthera and algae have all shown promise for methane production, but research is needed to prove their value. Designs for small-scale biogas generators are needed to suit the water plants available and the particular conditions of different countries.

Wolverton, B.C. and R.C. McDonald, Don't waste waterweeds. New Sci., 71(1013):318-20 1976

The authors describe the work being done to utilize water hyacinths to purify industrial and domestic wastes, and also report on the use of water hyacinths to produce biogas containing 60-80% methane, which is a promising substitute for natural gas. Research shows that 374 litres of biogas can be produced from 1 kg of dried water hyacinth. The fuel value of this gas is 21 000 BTU/m^3 compared with 31 600 BTU/m^3 for pure methane. A continuous supply of water hyacinths can be grown in domestic sewage lagoons where they perform an anti-pollution function. One hectare of water hyacinths fed on sewage nutrients can yield 0.9-1.8 tonnes of dry plant material/day. This biomass can produce 220-440 m^3 of methane with a fuel value of 7-14 million BTU. In addition, the sludge that remains after fermentation is a useful fertilizer because it retains most of the N, all of the P and other minerals. Water hyacinths which clog water ways in many developing countries have a lower protein content than cultivated hyacinths. But they are still very useful for biogas production. The Sudanese Government (with the assistance of NASA through the U.S. Academy of Sciences) is experimenting with small-scale digesters to process the thousands of tons of water hyacinths mechanically harvested from the White Nile.

Wolverton, B.C., R.M. Barlow and R.C. McDonald, Application of vascular aquatic plants
1976 for pollution removal, energy and food production in a biological system. In Biological control of water pollution, edited by J. Tourbier and R.W. Pierson, Jr. Philadelphia, University of Pennsylvania Press, pp.141-9

The authors describe and illustrate a proposed system for purifying industrial and domestic wastes by using the polluted water through a lagoon system. The last lagoon carries a crop of water hyacinth which extracts nutrients and other pollutants from the water. The system visualizes that the hyacinth is harvested regularly. The first process to which it is subjected is to be chopped into small pieces and then fed into a biogas converter. Then, after the yield of gas has been obtained, the residue of the hyacinths is processed to extract metals, for conversion to fertilizer, etc.

Wolverton, B.C., R.C. McDonald and J. Gordon, Bio-conversion of water hyacinths into
1975a methane gas. Part 1. NASA Tech.Memo., (TM-X-72725)

Laboratory experiments are described in which water hyacinths were fermented in anaerobic conditions and the yield of biogas and its content of methane measured. Biogas is the collective term for the mixture of gases evolved (mainly methane and carbon dioxide). It was found that preparation of the plant material, either as pieces 2.5 cm long, or macerated into a slurry, did not vary the amount of biogas evolved from a given sample. The temperature at which fermentation took place influenced the yield of biogas and the time lag before production began.

It was also found that if the water hyacinths had been grown in a solution containing nickel and cadmium the output of methane, and the proportion of methane in the biogas, were increased. The results are summarized in the following table:

Type of water hyacinth material (500 g fresh wt.)	Temperature (°C)	Time lag (days)	Yield of methane/g fresh material (ml)	Methane content in biogas (%)	Yield of biogas over 65 days (ml/day)
Slurry	25±5	8	7.9	61.1	-
Chopped (2.5 cm length)	25±5	8	6.4-11.0	57.2-61.5	-
Chopped	36	1	8.9	69.2	76.8
Chopped with Ni+Cd*	36	1	11.3	91.1	87.5

* Concentrations in hyacinth: Ni = 9.95 ppm; Cd = 12.66 ppm

The authors conclude that sample preparation of water hyacinth, either chopped or blended, had no significant effect on biogas and/or methane production. Incubation of the experimental units at 36°C increased not only the rate of biogas production but also the methane content of the total biogas produced in these experiments. Pollution of the water hyacinths by two toxic heavy metals, nickel and cadmium, actually increased the rate of methane production and improved the methane content of the biogas evolved in the anaerobic decomposition of the contaminated plants.

2. Paper and Building Materials

Bakshi, T.S., 1964 Control of Vossia cuspidata. An aquatic weed of growing importance. Span, 7(1):37-9

Discussing the control and uses of the aquatic grass Vossia cuspidata in Sierra Leone, the author cites literature suggesting that the plant gives a low yield of short-fibred pulp of poor strength. Therefore paper made from it would not be suitable for purposes for which high mechanical strength would be required (e.g. wrapping paper), but it could be used in the manufacture of printing and writing papers.

Chivu, A.I., 1968 Practical experiment in the cropping of reeds for the manufacture of pulp and paper - economic results. In Pulp and paper development in Africa and the Near East. Rome, FAO, vol.2:877-99, FAO Access.No. 03953-68-MR

The author describes the harvesting and processing of the reeds (Phragmites communis) which occupy about 50% of the Danube delta. At the time of writing the cropping capacity was about 350 000 t/year. The capacity of the industry is 100 000 t of pulp per year. Chivu says that the pulp from the reeds is better and cheaper than the pulp derived from straw and bush, and has characteristics suitable for the manufacture of artificial fibres. The use of pulp from reeds in the proportion of 30-50% in the composition of printing and writing papers leads to qualitative improvements in the paper without involving any technical difficulties. The use of reeds has saved large amounts of timber which otherwise would have had to be used for paper.

Chivu also includes an economic and technical review of the processes of paper making with reeds.

*Gloor, A.M. and R.P. Gloor, 1950 Paper from water hyacinth. Australian patent 138, 426. August 21, 1950

Fresh leaf stalks (and optionally leaves) of Eichhornia crassipes are boiled about 25 minutes in aqueous KOH (5-10°Be') filtered, washed until neutral, filtered, sized with 20% solution of dammar resin in 90°EtOH, diluted to paper making concentration and formed into high-strength paper.

*India, Council of Scientific and Industrial Research, 1952 The wealth of India. Vol. 3. Raw materials. New Delhi, CSIR, pp.130-4

Reviewing various uses for water hyacinth the article states: "Attempts have been made to utilize the plant as a raw material for paper, plastics and other commercial products, but so far no industry based on water hyacinth appears to have been established. The manufacture of paper from the dried weed has been attempted in Bengal. The fibrous stem, constituting about 40% of the whole plant, is suitable for paper making. The addition of jute or cotton fibres to the extent of 8-10% on the weight of the pulp is considered necessary as the paper prepared from the stems alone is translucent. The pulp may be pressed into boards and used for papier mache, or mixed with cement and whiting and moulded into tiles. A plastic material suitable for the production of moulded articles and boards has been prepared from water hyacinth."

Nag, B., 1976 The destruction of water hyacinth by utilization. In Aquatic weeds in South East Asia, edited by C.K. Varshney and J. Rzoska. Proceedings of a Regional Seminar on noxious aquatic vegetation, New Delhi, 12-17 December, 1973. The Hague, Dr. W. Junk B.V. pp.383-5

The standard tests for artificial cellulose prepared from the non-cellulosic tissues of water hyacinth indicate that the weed could be used for manufacturing paper and other cellulosic materials such as artificial silk (rayon). (From Weed Abstracts)

Nolan, W.J. and D.W. Kirmse, 1974 The papermaking properties of waterhyacinth. Hyacinth Control J., 12:90-7

The authors subjected water hyacinth plants to processes which extracted the vascular bundles. The yield obtained of suitable raw material for pulp was a maximum of 20% of the original plant tissue. Pulping with sodium sulphite, and mixtures of sulphite and bisulphite, resulted in the highest yields - as high as 80-88% of material fed to the digesters. However at yields higher than 75% pulps were undercooked and could not be converted to papers of acceptable strength. The highly alkaline processes using sodium hydroxide and Kraft liquors resulted in pulps of much lower yields, mostly in the range of 40-50%.

Pulp yields of 65-75% resulted in paper handsheets of reasonably high strength. These apparently high yields, when converted to percentages of the original water hyacinth plant, were reduced to the very low values of 13-15%, since only a maximum of 20% of the whole plant was available to the pulping operation.

A serious defect in the hyacinth pulp was the extremely low "freeness", or drainage rates, of the pulp compared to pine pulps. This would make the pulp unacceptable to the paper industry, even if fibre strength had been found superior to those of pine pulps. Additional disadvantages of hyacinth pulp were darkening and shrinking on drying. The shrinking led to erratic strength values and wrinkling of the dried sheets. All these findings led the authors to the conclusion that commercially acceptable paper pulps cannot be made from water hyacinths.

Steenberg, B., 1968 Papyrus: problems in its utilization for pulp and paper making. In Pulp and paper development in Africa and the Near East. Rome, FAO, vol.2: 865-76, FAO Accession No. 03952-68-MR

The author discusses the use of Cyperus papyrus and C. antiquorum for paper manufacture. He describes the ancient use of these plants for papyrus which was made by strips of the pith being laid together, overlapping, with a second series of strips applied at right angles to the first layer. On pressing and drying the strips adhered together to form the papyrus sheet.

The stem is the part concerned with paper making. It constitutes about 80% of the fresh weight of the aerial part of the plant, the remainder being the inflorescence. The inflorescence is about 33% of the dry weight of the plant in the case of C. antiquorum, and about 25% for C. papyrus. The pith of the stem weighs about 30% of the total weight of C. antiquorum but can amount to up to 80% of C. papyrus. When dry the cells collapse, making them useless for conventional paper making.

Although the stands of papyrus, as seen from the water, give an impression of covering large areas they do not normally extend from the water front for more than about 30 m. Beyond this range smaller water plants such as Vossia, Glyceria and other Cyperaceae take over.

A reasonable estimate of the yield of papyrus stands is given as 20 t of dry matter/ha, though double this figure has been reported. From this 20-35% of pulp can be expected, which implies a yield of from 2-5% of the fresh weight.

The author cites the manufacture of building boards from papyrus in Uganda. Studies on the use of papyrus for hardboard have also been carried out.

Steenberg points out that papyrus is similar in value, for the production of pulp, to grasses and straw, the main question being whether supplies would be adequate. For a moderate-sized pulp mill producing 100 t/day, about 20 ha/day would have to be harvested. He concludes that the economic and technical problems of production of papyrus pulp seem overwhelming because of the difficulties of harvesting, the need for heavy machinery to separate the pith, and the lack of any valuable by-products apart from the pulp itself.

3. Medicinal

Sculthorpe, C.D., 1967 The biology of aquatic vascular plants. London, Edward Arnold, 610 p.

The author has searched the ancient literature for medicinal uses for aquatic plants (pp.517-520). The following summarizes his findings:

Acorus calamus, the sweet flag, a native of South-East Asia but naturalised in Europe, has had medicinal preparations made from the rhizome. These have been used for treatment of eye diseases, indigestion and colds. Even up to modern times it has been used as a general stimulant.

Pistia stratiotes was used in Egypt for healing skin diseases and wounds. In India it is used similarly after boiling the leaf juice in coconut oil. A preparation from the leaves in sugar and rosewater is taken for coughs and asthma. The roots provide a laxative and diuretic. Ringworm is treated by rubbing the ashes into the scalp.

Sculthorpe lists about 25 aquatic plants from which preparations have been made to treat a wide variety of complaints. Of these it is possible that some do actually contain active principles, about 15 different alkaloids having been isolated from members of the Nymphaeaceae. The long established use of the leaves of Nuphar as styptics, and infusions of the rooted parts as a lotion for skin ailments probably owes its success to the high concentration of tannic acid in these organs. Some species containing toxic substances can have unfortunate effects. For example, the acrid extracts of Alisma plantago-aquatica could cause complete paralysis. The use of Oenanthe aquatica for various complaints could cause narcotic poisoning.

Wasuwat, S., 1970 Extract of Ipomoea pes-caprae (Convolvulaceae) antagonistic to histamine and jelly fish poison. Nature, Lond., 225:758

The uses of Ipomoea pes-caprae, abundant in Thailand close to the sea, are described. The author says that the leaves are used either boiled for external application as an anodyne, or powdered and used as an ointment against sores and ulcers. Thai fishermen use the plant as an antidote to jelly fish stings. Analysis has revealed that the plant does contain an active principle (IPA) that is antagonistic to jelly fish poison and is also mildly antihistaminic. The yield of IPA from leaves was

about 0.05%. It is a volatile ester. Though it is less effective as an antihistamine compared with two recognized antihistamine drugs, it has about the same antagonistic effect against jelly fish poison.

Zafar, A.R., 1976 Economic significance of certain species of Scirpus sp. In Aquatic weeds in South East Asia, edited by C.K. Varshney and J. Rzeska. Proceedings of a Regional Seminar on noxious aquatic vegetation in tropics and sub-tropics, New Delhi, 12-17 December, 1973. The Hague, Dr. W. Junk, B.V. pp.387-91

The author cites evidence from the literature that the powdered underground parts of Scirpus grossus are useful in treating the human ailments dyspepsia and dysentery in India. It is possible that these parts accumulate benzenoid compounds.

4. Other

Moore, A.W., 1969 Azolla: biology and agronomic significance. Bot.Rev., 35(1):17-34

In a review of the literature on the water fern Azolla Moore cites a report (1926) that in central Africa certain tribes dried and burned water plants (Pistia, Lemna and Azolla) and by mixing fat with the ashes, rich in potassium, produced a crude soap.

Early in the century it was thought that Azolla could be useful for mosquito control when encouraged to form a dense mat over ponds. This gave the plant the name "mosquito fern". This attribute has, however, not been established.

*Neogi, S. and K. Rajagopal, 1949 A method for the production of carotene concentrate from water hyacinth (Eichhornia crassipes). J.Sci.Ind.Res., India, 8B(7):119-21

The methods of production of carotene from fresh water hyacinths are described. Lots of 1 200 g of fresh leaves were dehydrated by several procedures. In one set of experiments the untreated leaves were dried at 60°C. In another set, leaves were chopped and blanched (immersion in boiling water for 3 minutes) and dried at 60° ± 5°C. The carotene contents of samples treated by the two methods are as follows:

Carotene content (on dry basis) (mg/100 g)		
Untreated	Blanched	% Difference
16.8	28.1	40.1
19.4	35.3	45.0
20.9	34.2	41.7
18.1	31.8	42.8
21.2	36.2	41.4

Blanching hastens dehydration and raises the yield of carotene by about 42%.

Petroleum ether (b.p. 40-60°C) was used for Soxhlet extraction, and high-boiling petroleum ether (b.p. 80-100°C) was used for direct heating. The average yield of carotene is shown in the following table:

100 g of Dried leaves extracted for 6 hours

Moisture (%)	Carotene content (mg)	Petroleum ether (40–60°C) Yield (mg)	Petroleum ether (40–60°C) Recovery (%)	Petroleum ether 80–100°C) Yield (mg)	Petroleum ether 80–100°C) Recovery (%)
86.4	34.7	19.9	55.4	29.6	85.3

It is seen that a maximum yield of 85.3% is attainable when extractions are made by direct heating over a water bath employing high-boiling petroleum ether.

Soda ash is cheap and selective in adsorption. Of the adsorbed materials, the carotenoid pigments, being the least adsorbed constituents of the mixture, passed through, while the contaminants, chlorophylls and allied chromogens remained bound to the adsorbent. There was little decomposition of the pigments during the chromatographic analysis. Each tube was uniformly packed with well mixed soda ash and magnesia (6:1). Petroleum ether (40–60°C) was forced through the tubes until the columns were covered with the solvent. The process was continued until the washings began to show the brownish colour of chlorophylls.

The orange and light yellow bands were taken together as total carotenes.

To determine the yield of carotene obtainable, 3 kg of fresh, chopped leaves were blanched and dried at 60°C. The dried leaves were pulverized and extracted with petroleum ether (b.p. 80–100°C) and then separated chromatographically. The averaged results are given in the table below:

Extract from 3 kg fresh leaves of water hyacinth

Moisture (%)	Carotene content (mg)	Yield (mg)	Recovery (%)
85.7	165.2	140.8	85.7

Sculthorpe, C.D., The biology of aquatic vascular plants. London, Edward Arnold, 610 p. 1967

Reviewing the literature, the author cites various uses for aquatic plants (pp.521-522).

Nymphaea alba and Nuphar sp., because of their content of gallic or tannic acid, both of which have mordanting properties, have been employed in several European countries in dyeing and tanning, and also in brewing. Leaves of Menyanthes trifoliata have been used as a substitute for hops in brewing beer. In India Aeschynomene aspera provides a pith similar to balsa for various artifacts and for life jackets. The culms or leaves of Cyperus spp., Schoenoplectus spp. and Typha spp. are still in use in many parts of the world for weaving and basketry. The hairs of female Typha flowers were used to stuff pillows. The culms of Arundo donax have provided reeds for woodwind instruments for centuries. This plant has also been used to provide cellulose for rayon and has been considered for paper manufacture. It is also used for weaving, thatching and making walking sticks and fishing rods. Cyperus papyrus, in addition to being used for making papyrus, was made into ropes, canvas, and sails.

Sculthorpe refers to the Romanian industry based on Phragmites communis for pulp from which not only paper is made but cardboard, cellophane and various synthetic fibres. By-products include reed-blocks, fibre boards, furfural, alcohol and fuel, insulation material and fertilizer.

*Sheikh, N.M., S.A. Ahmed and S. Hedayetullah, The effect of root extraction of water
1964 hyacinth (Eichhornia crassipes) on the growth of microorganisms and mash kalai (Phaseolus mungo var. Roxburghii) and on alcoholic fermentation. Pak.J.Sci.Ind.Res., 7:96-102

The authors extracted substances from the roots of water hyacinths. They found that these substances, which were stable to heat up to 100°C, promoted the growth of fungi, yeasts and the roots of seedlings of Phaseolus mungo. By fractionation of the substances it was determined that organic compounds present were without effect and that therefore the growth promotion effects observed were due to inorganic compounds. The authors suggest that these inorganic substances extracted from water hyacinth could be used to promote yeast production and alcoholic fermentation.

*Sircar, S.M. and R. Chakraverty, The effect of gibberellic acid and growth substances
1962 from the root extract of water hyacinth, Eichhornia crassipes, on rice and gram. Indian J.Plant Physiol., 5:1-2

The authors' summary of their work with water hyacinth root extracts on the growth of rice is as follows:

"The effect of gibberellic acid (GA) and growth-regulating substances of the root extract of water hyacinth (RWH) on the growth and flowering behaviour of rice and gram were investigated. The treatments consisted of 100 ppm GA, root extract of water hyacinth in the concentration of 1:5 and 100 ppm GA plus the root extract mixed in the proportion of 1:1 (GA+RWH). The spraying commenced with 40-day-old plants and continued once a week till the time of flowering. All the treatments resulted in an increased height in both rice and gram plants. Death of the apical meristem after GA treatment in gram was noted. GA further decreased tillering in rice and lateral branches in gram, while RWH and GA+RWH increased their growth to a great extent. All the treatments induced flowering earlier than the control and the maximum earliness was noted with plants treated with GA. Although GA increased the length of the spike in rice it was associated with a low percentage of grain formation and the grain yield per plant was greatly reduced. Between the treatments RWH showed the best effect as the yield and percentage of grains was greater than with other treatments."

*Sircar, S.M. and A. Ray, Growth substances separated from the root of water hyacinth
1961 by paper chromatography. Nature, Lond., 190(4782):1213-4

In this paper the authors describe the treatment in the laboratory of the roots of water hyacinth to extract substances which, they conclude, are additional to indole compounds or gibberellins.

*Villadolid, D.V. and D.M. Bunag, New uses for water hyacinths. Philipp.Fish.Yearb., 1953 1953:80-1, 241-2

Discussing the various uses of the water hyacinth the authors state that during the war the plant was utilized for the manufacture of soft soap by burning the plant and getting the lye from the ash by leaching.

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Fisherman setting net using water hyacinth as floats on Rawa Pening lake, Central Java, Indonesia

XII. POSTSCRIPT

This handbook has not considered all fresh-water aquatic plants, nor all possible uses for them. This is probably, in part, because some publications may have inadvertently been overlooked, and in part because many ways of utilizing aquatic plants have yet to be published. It is to be hoped that readers of this book who notice such omissions will publish what they know and draw attention to valuable but perhaps not widely known publications so that the information they contain can, in due course, be collated and made available for all who are concerned with the problems of aquatic plants and the potential ways in which they can be put to use.

The U.S. National Academy of Sciences is performing valuable service in this way. Frequent reference has been made in this handbook to their 1976 publication. Those who are not specialists in this field, and who avail themselves of the wealth of information compiled by Sculthorpe (1967), may be surprised at the large numbers of aquatic plants which exist and their wide diversity of form, function and habitat. Sculthorpe's book will remain an essential reference for many years, and a study of its pages will reward anyone who has marvelled at the charm and beauty of plants which live in water. An admiration which may reluctantly be acknowledged even by those who have struggled to force canoes and boats through dense mats of choking water weeds, or have suffered the losses, ill health and danger from explosive occupation of water by some exceptionally vigorous plants. In these circumstances - and millions of people have to endure them - it is not easy to share the admiration of water plants held by those who have fortunately not had to suffer from them.

Sculthorpe writes (p.503): "In India, China and Japan several decorative water plants have been held in the highest esteem since the earliest times. The immense admiration of the beautiful flowers of lotuses and waterlilies, above all others, is reflected in their frequent portrayal on fabrics and tapestries, pottery and metalwork, monuments and tombs, temples and public buildings, and in their adoration in prose and verse."

This admiration spread to the western world where water gardens were developed to a high form of art. A consequence of this has been the distribution round the world of many water plants, some, like the water hyacinth - the most notorious of all - spreading prolifically and dangerously.

Now it seems the circle may have almost completely turned. Pampered and admired plants became pests and now, with greater insight, are again seen (but for different reasons) as valued and potential assets to mankind.

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